UK Hydrological Review 2003

2nd Edition

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

2003

UK HYDROLOGICAL REVIEW

This Hydrological Review, which also provides an overview of water resources status throughout 2003, is a reformatted version of the original commentary released as a web report in 2004. Some of the data featured in this report, particularly the more extreme flows, may have been subsequently revised.

The annual Hydrological Reviews are components in the National Hydrological Monitoring Programme (NHMP) which was instigated in 1988 and is undertaken jointly by the Centre for Ecology & Hydrology (CEH) and the British Geological Survey (BGS) – both are component bodies of the Natural Environment Research Council (NERC). The National River Flow Archive (maintained by CEH) and the National Groundwater Level Archive (maintained by BGS) provide the historical perspective within which to examine contemporary hydrological conditions.

A primary source of information for this review is the series of monthly UK Hydrological Summaries (for further details please visit: http://www.ceh.ac.uk/data/nrfa/nhmp/nhmp.html). The river flow and groundwater level data featured in the Hydrological Summaries – and utilised by many NHMP activities – have been provided by the Environment Agency (EA), Natural Resources Wales - Cyfoeth Naturiol Cymru, the Scottish Environment Protection Agency (SEPA) and their precursor organisations. For Northern Ireland, the hydrological data were sourced from the Rivers Agency and the Northern Ireland Environment Agency. The great majority of the reservoir level information has been provided by the Water Service Companies, the EA, Scottish Water and Northern Ireland Water (formerly Water Service). The generality of meteorological data, including the modelled assessments of evaporation and soil moisture deficits featured in the report, has been provided by the Met Office. To allow better spatial differentiation the monthly rainfall data for Britain are presented for the regional divisions of the precursor organisations of the EA and SEPA. The Met Office monthly rainfall series are Crown Copyright and may not be passed on to, or published by, any unauthorised person or organisation. The provision of the basic data, which provides the foundation both of this report and the wider activities of the NHMP, is gratefully acknowledged.

Authors

This report was compiled by: Terry Marsh and Felicity Sanderson.

Publication Address

Centre for Ecology & Hydrology
Maclean Building
Benson Lane
Crowmarsh Gifford
Wallingford
Oxfordshire
OX10 8BB
UK
General and business enquiries: +44 (0)1491 692599
E-mail: nrfa@ceh.ac.uk

For further information about the National Hydrological Monitoring Programme please visit: http://www.ceh.ac.uk/data/nrfa/nhmp/nhmp.html

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Hydrological Review of 2003

2003 Summary

After five successive years with above average rainfall in many parts of the country, 2003 registered well below average totals in all regions; for the UK as a whole it was the driest year since 1955. Large rainfall deficiencies developed through the spring and an exceptionally arid late summer/early autumn established severe and widespread drought conditions by late September. Significant water resources stress was experienced but the resilience of the UK, even to outstanding within-year rainfall deficiencies was well demonstrated. This resilience is underpinned by a range of water management strategies and drought response mechanisms but, in 2003, relatively wet conditions early and late in the year were also especially helpful. January was particularly unsettled with notable floods experienced in most of southern Britain. But the abundant runoff served to replenish reservoir stocks and groundwater resources, establishing a buffer against the impact of the subsequent drought conditions. Nonetheless, the wet end to the year was very welcome – helping to eliminate seasonally high soil moisture deficits and initiate a much delayed recovery in river flows and aquifer replenishment rates. After a notable deterioration in the water resources outlook over the nine months to October, surface and groundwater resources recovered smartly (in most areas) leaving overall resources well within the normal range by year end.

Record temperatures in August – a feature across much of Europe – provided a dramatic focus for another warm year. However, October was notably cool and average temperatures for 2003 as a whole were marginally below those of a number of recent years; provisionally, 2003 ranks 7th warmest in the Central England Temperature series which begins in 1659[1]. Correspondingly, potential evaporation demands again exceeded the average across much of the UK. In most of northern and western Britain, this was true of actual evaporation losses also but 2003 totals were considerably below average throughout much of the English Lowlands where transpiration losses were restricted, over lengthy periods, by notably high soil moisture deficits. By the early autumn, exceptionally dry soil conditions were very widespread; concern about the prospective foreshortening of the 2003/04 aquifer recharge season was only allayed by sustained wet conditions from mid-October through into January 2004.

Apart from a few major reservoirs (e.g. Colliford in Devon) most impoundments began 2003 at, or close to, capacity. Drawdown of some large gravity-fed reservoirs was necessary to provide scope for flood alleviation during the very wet conditions in late December 2002 and early January 2003. Figure 1 shows the variation in overall stocks for a representative network of major reservoirs across England and Wales for the 1995-2003 period. The late winter and early spring of 2002/03 saw a brisk decline in stocks but above average May/June rainfall provided a modest, but important, seasonally late boost to reservoir stocks. Thereafter, a steep decline in stocks became established. This continued into the autumn and, by early October, overall stocks were only a little above 50% of capacity – their lowest since the autumn of 1995. Stocks were particularly depressed in southern England and the North-West – stocks were seasonally very low in parts of Scotland and Northern Ireland also. The sustained decline in surface water resources triggered calls for restraint in water use and a number of water conservation and management measures were introduced to conserve resources and help maintain dwindling river flows; however no Drought Orders were needed. The resources outlook remained rather fragile until a steep recovery in reservoir levels gained momentum through November. The increase in overall stocks for England and Wales during December was the greatest for any single month on record (in a 16-year series); this late surge allowed surface water resources to return to normal levels entering 2004.

A guide to the variation in annual runoff for England and Wales, Scotland and Northern Ireland – expressed as percentage departures from the long term mean – is shown on Figure 2. The runoff assessments are based on outflows from representative networks of gauging stations monitoring outflows from major river basins; the estimates for the first few years featured on each plot are less reliable due to the relatively sparse monitoring network at the time. Total outflows from England and Wales in 2003 were around 25% below average, markedly lower than for the previous five

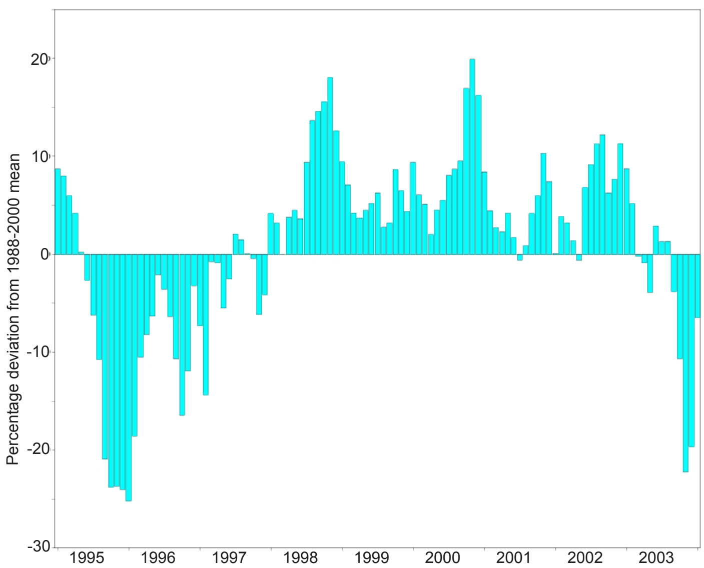


Figure 1 *A guide to England and Wales reservoir stocks 1995-2003.*

Data sources: Water Services Companies and the Environment Agency.

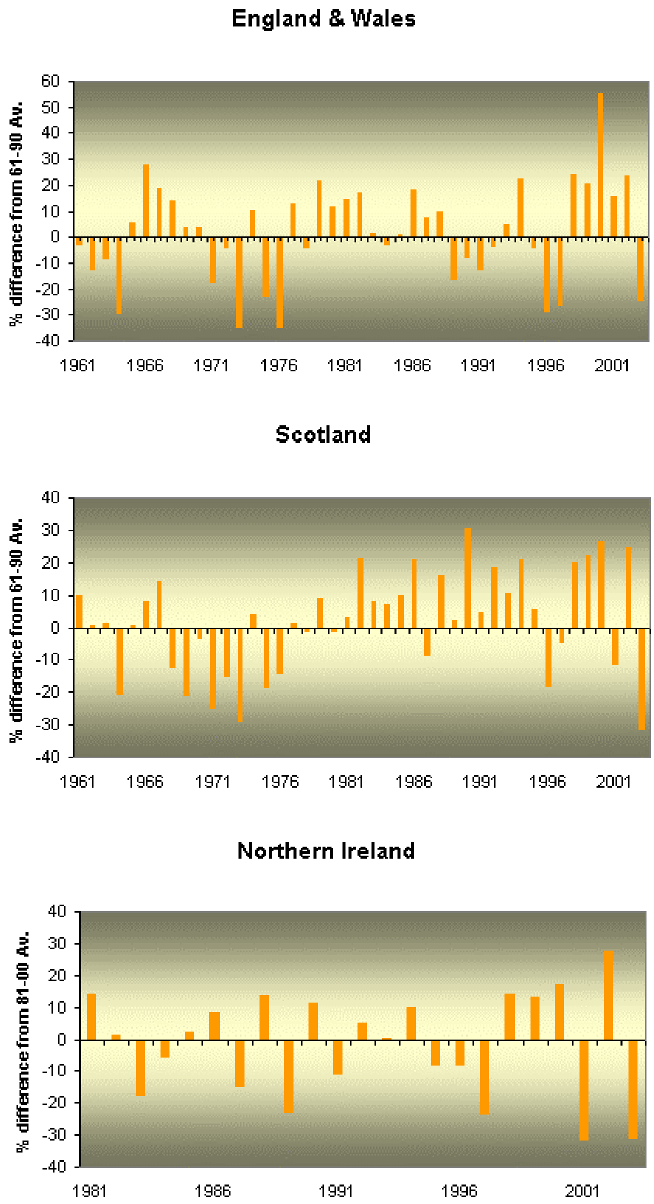


Figure 2 *Index of total runoff 1961-2003.*

years and the 6th lowest runoff in the 43-year series. Runoff across Scotland was even more depressed with estimated total outflows eclipsing 1973 as the lowest on record, and in notable contrast with the above average runoff which has characterised most of the post-1980 period. In Northern Ireland, where a province-wide gauging station network has been in place only since the late 1970s, the 2003 runoff total was also notably low, closely approaching the lowest on record – registered in 2001.

Although catchment runoff totals for 2003 were notably low in many areas, river flows generally exhibited an abnormally large range particularly in southern Britain where the year began with widespread floodplain inundations. A significant number of new maximum daily flows were reported for gauging stations in the South-East and the Thames – in its middle reaches – recorded its highest flow since March 1947. Further spates occurred in February but these heralded very protracted river flow recessions which resulted in new minimum recorded flows for April in many catchments. Flows picked up in most rivers during the late spring and generally remained within the normal range through the early summer. However, the continuation of the seasonal recession well into the autumn resulted in flows approaching long term September/October minima over wide areas. In a few rivers (e.g. in the Tweed basin) new minimum daily mean flows were reported and, more widely, monthly flows amongst the lowest three or four on record (for any month) were recorded. A spatially uneven recovery began in mid October and runoff rates increased rapidly in the early winter. Nonetheless, many rivers across the UK registered 2003 runoff totals in the lowest decile with a significant minority (e.g. in eastern Scotland) establishing new annual minimum runoff totals.

Across most of the major aquifer outcrop areas – which are found principally in eastern and southern England – groundwater resources were exceptionally healthy over the 1998-2002 period; record groundwater levels were registered in early 2001 in many areas. Abundant recharge over the last three months of 2002 resulted in early 2003 groundwater levels also approaching the highest on record – particularly in the Chalk where, briefly, there was a high risk of a repetition of the sustained groundwater flooding experienced two years previously. A very dry late-winter banished these concerns and triggered an early start to the 2003 seasonal recession in groundwater levels. These were generally steep and protracted, but having mostly begun from near seasonal maxima, levels in most index wells and boreholes remained appreciably above average well into the summer. This underlines the value of groundwater in moderating the impact of rainfall deficiencies through the summer half-year but, unusually, the 2003 recessions persisted into the late autumn, and longer in the slowest-responding aquifer units. Consequently, groundwater levels in most index wells and boreholes had declined to well within the normal range by the late autumn and the delayed seasonal onset of recharge raised concerns about the outlook for 2004. Sustained rainfall over the last 10 weeks of the year – more than twice the average over some outcrop areas – allowed recoveries to be initiated and overall groundwater resources were around average entering 2004.

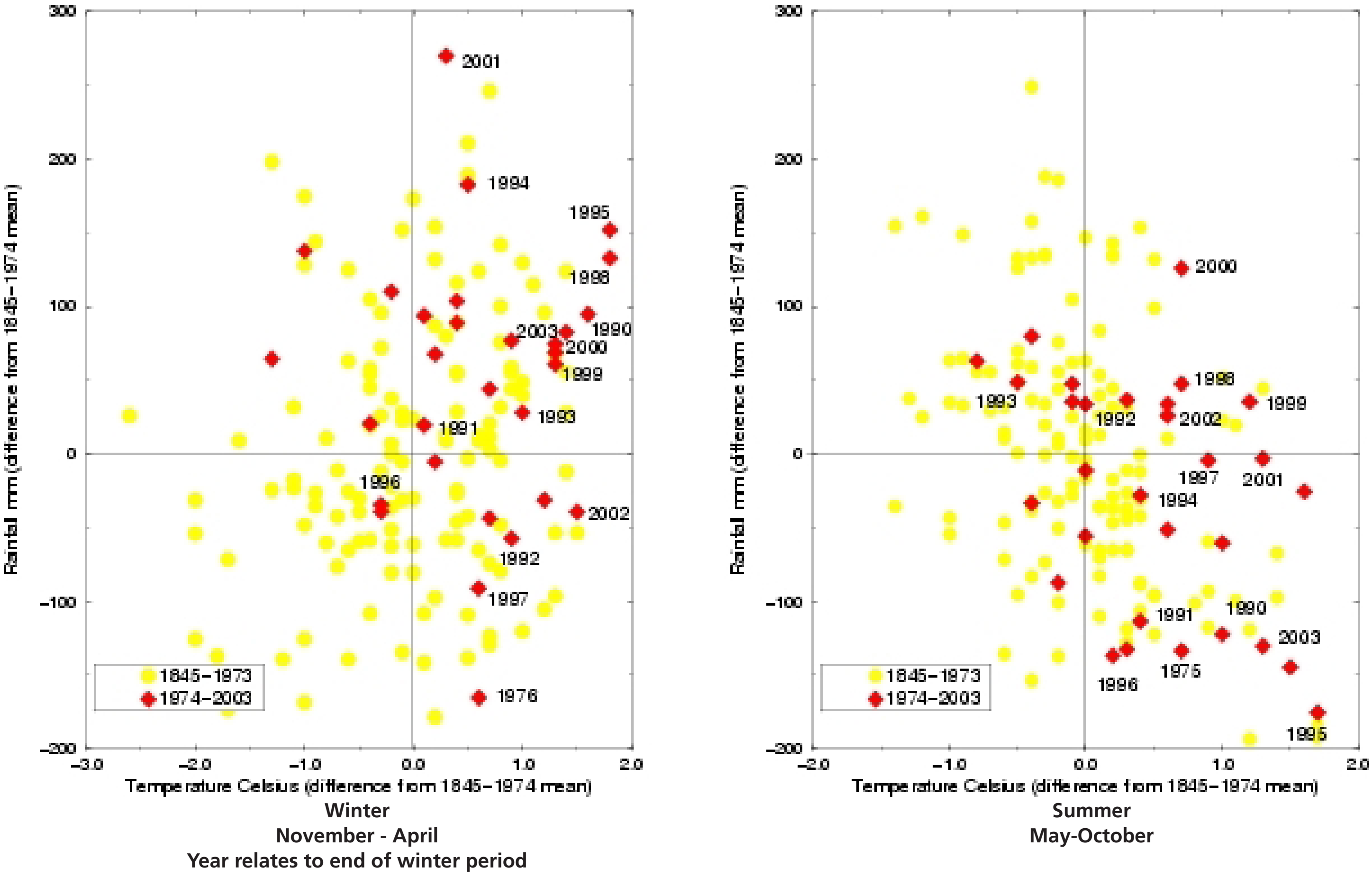


Figure 3 *England and Wales rainfall and temperature anomalies 1845-2003.*
Data sources: Central England Temperature series/Hadley Centre

The recent past

Temperatures and evaporation patterns during 2003 provided an insight into conditions which may become more familiar in a warmer world. The more distinctive partitioning of winter (Nov-April) and summer (May-Oct) rainfall for England and Wales (for 2003-04) is also consistent with a number of favoured climate change scenarios. Figure 3 illustrates winter and summer rainfall and temperature anomalies from England and Wales from 1845 – the plotting positions for the most recent 30-year period appear as red diamonds. 2002-03 adds to a cluster of mild, wet winters and dry, warm summers over the recent past. However, the UK climate exhibits large year-on-year variability and, over longer timespans, wet and dry periods can show considerable persistence. Any short-term climatic tendencies should therefore be treated with caution.

The last 15 years has seen a modest extension in the range of recorded variation in river flows for some seasons – the autumn particularly. This is largely a reflection of the notable flood episodes over the 1998-2003 period (and 1989-1994 across much of Scotland) and the impact of drought conditions in the early and mid-1990s. At the national scale, average runoff for the post-1990 period is considerably above average. This is almost entirely a consequence of enhanced winter half-year river flows. For the late spring and early summer months 1991-2003 average flows have been closely comparable with the 1961-90 mean but considerably below average for August and September. Given the substantial year-on-year variation in monthly flows, appreciable departures from standard averages are to be expected when comparisons of this type are undertaken.

In water resources and river flow terms the evaporation rates in 2003 were particularly interesting. Unsurprisingly, evaporative demands were amongst the highest on record across most of the country. However, the exceptional dry soil conditions through the late summer and early autumn restricted actual evaporation losses substantially. Consequently, annual water balances for many of the driest catchments were not unusual, emphasising that increasing potential evaporation demands may not necessarily be associated with declining water resources. Certainly, notably dry autumn soils may delay the seasonal recovery in river flows and groundwater levels which, in the event of a dry winter, could jeopardise the water resources outlook. But at the national scale, positive trends in temperature and annual potential evaporation totals over the last 15 years have not been accompanied by any decline in mean annual catchment runoff totals or any reduction in mean groundwater levels.

Rainfall

The year in brief

2003 national and regional rainfall totals for the UK, together with the corresponding percentages of the 1961-90 average, are shown on Figure 4; individual monthly and half-yearly figures are given in Table 1. For the UK as a whole, the 2003 rainfall total was around 18% below average with significant deficiencies characterising all regions – typically in the 15-25% range with the greatest anomalies in north-eastern Britain. England and Wales registered its driest year since 1975, Scotland its driest since 1972 whilst Northern Ireland reported its second lowest rainfall (after 2001) in the last 29 years. The distribution of rainfall through the year was also very unusual: January and December were very wet but many localities reported 8 or 9 months with below average rainfall. The very damp start to 2003 continued a wet episode which began in the autumn of 2002. Western Scotland aside, regional rainfall totals for the October 2002-January 2003 period (Figure 5) exceeded the average by a significant margin – helping to ensure that water resources were well placed to withstand the ensuing drought conditions.

The most significant characteristic of the 2003 synoptic patterns over the UK was the relative rarity of rain-bearing frontal systems over the late winter and early spring period, and again during the late-summer and early autumn. The scale of the resulting rainfall deficiencies is illustrated on Figures 6 and 7. Despite considerable late-April rainfall, the February-April total was the lowest for the UK as a whole since 1956 with large parts of the English lowlands reporting only a little over 50% of average rainfall. Even greater deficiencies characterised the August-October period which, for the UK, was the third driest on record. Some areas in central southern England registered less than 40% of average rainfall – such deficiencies correspond to

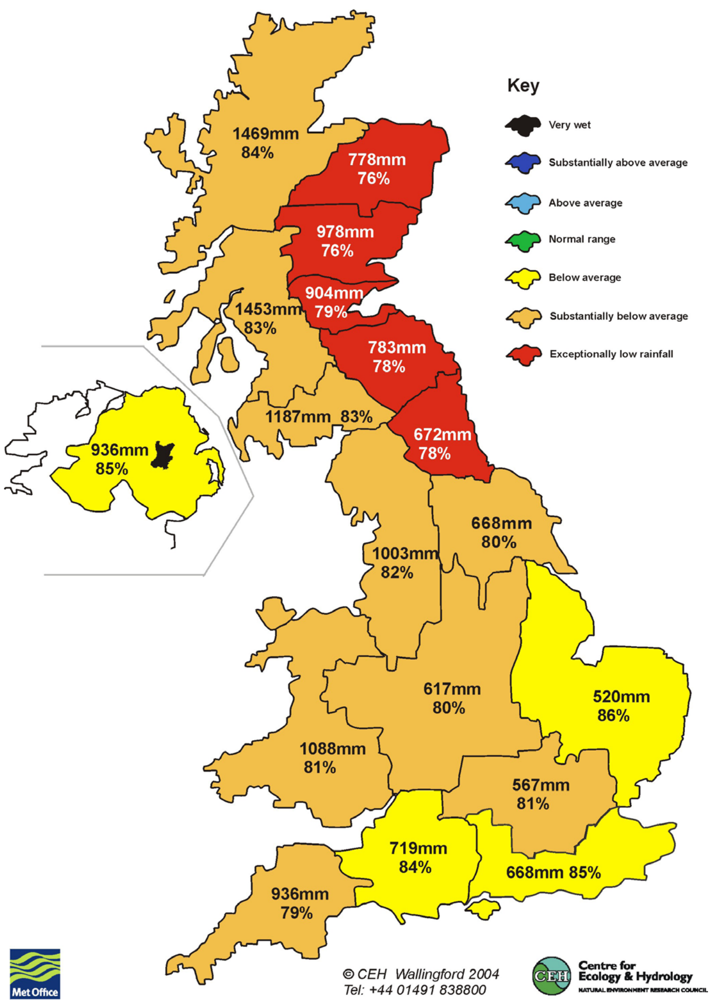


Figure 4 *Annual rainfall for 2003 in mm and as a percentage of the 1961-90 average.*

Data source: UK Met Office.

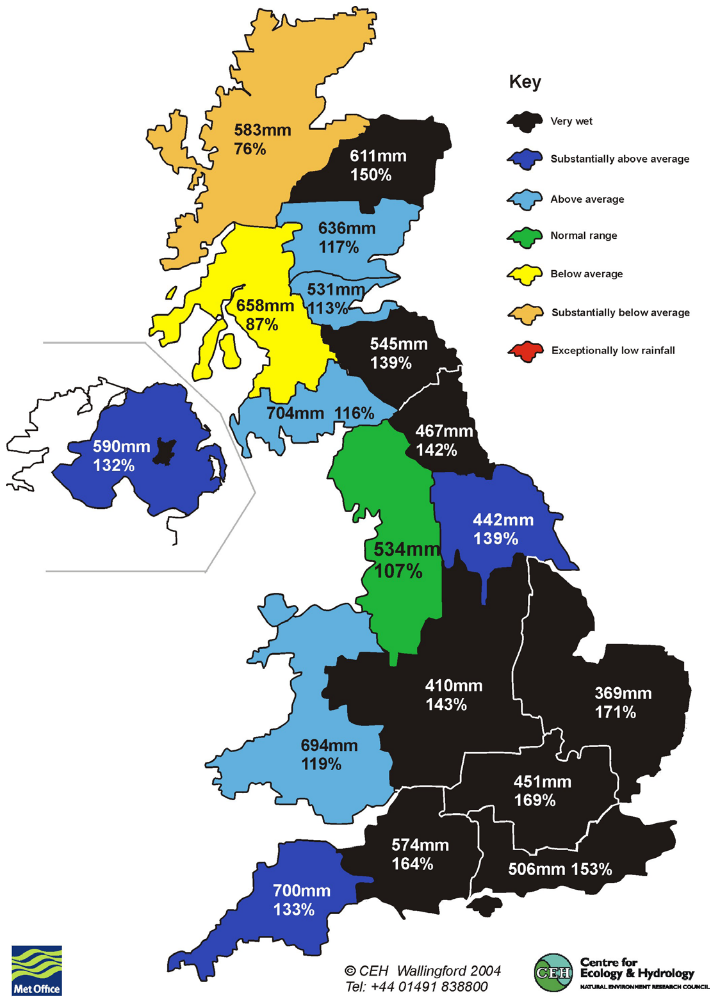


Figure 5 *October 2002-January 2003 regional rainfall totals in mm and as a percentage of the 1961-90 average.*

Data source: UK Met Office.

Table 1 *2003 Rainfall in mm as a % of the 1961-90 average.*

Data source: UK Met Office.

2003		**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Year**	**Oct-Mar 2002/03**	**Apr-Sep 2003**
United Kingdom	mm	114	48	54	50	98	71	78	27	54	64	120	122	901	642	378
	%	101	62	58	75	137	99	106	30	54	58	106	105	82	103	80
England and Wales	mm	86	39	39	45	75	67	76	18	37	58	100	100	739	580	317
	%	95	60	53	76	118	106	121	23	47	67	109	105	82	116	78
Scotland	mm	170	63	83	60	137	75	80	46	85	79	160	168	1206	750	483
	%	109	60	65	74	158	88	84	39	59	49	102	108	82	87	79
Northern Ireland	mm	108	68	48	53	128	86	93	23	66	52	115	96	936	707	448
	%	93	84	53	79	175	117	131	24	66	46	108	87	85	114	93
North West	mm	99	55	66	61	120	76	94	21	88	52	131	141	1003	654	461
	%	83	69	68	86	159	93	108	19	75	41	104	112	82	97	85
Northumbrian	mm	93	26	37	33	81	72	51	17	55	53	60	93	672	531	310
	%	111	44	52	57	130	116	76	21	75	69	69	113	78	115	76
Severn Trent	mm	61	29	33	43	69	67	67	18	28	55	58	90	617	471	292
	%	86	52	54	76	115	112	122	26	43	83	80	115	80	117	80
Yorkshire	mm	77	32	32	42	75	89	57	23	48	42	69	82	668	506	334
	%	97	55	47	71	124	144	92	30	68	56	84	99	80	114	86
Anglian	mm	76	17	19	25	47	72	57	7	21	41	75	62	520	406	230
	%	149	45	42	54	97	139	113	13	43	81	129	111	86	135	76
Thames	mm	82	25	24	35	47	49	50	11	15	38	120	71	567	500	206
	%	125	54	42	68	83	89	101	18	25	60	182	100	81	135	62
Southern	mm	87	34	24	35	44	45	59	22	12	59	154	93	668	563	217
	%	107	62	38	66	81	83	122	38	18	73	180	112	85	126	64
Wessex	mm	90	43	34	43	56	50	88	17	12	62	125	99	719	652	265
	%	100	66	48	80	90	88	164	26	16	76	148	105	84	134	72
South West	mm	103	85	43	62	80	68	109	25	27	90	110	134	936	827	371
	%	74	83	43	89	109	98	154	28	29	77	86	95	79	114	80
Welsh	mm	110	61	73	75	120	69	119	23	57	91	136	154	1088	829	464
	%	76	61	67	91	142	85	148	22	48	65	94	98	81	105	84
Highland	mm	231	72	109	68	163	87	79	62	102	111	169	215	1469	763	561
	%	128	57	69	72	174	88	74	48	60	58	86	111	84	73	81
North East	mm	120	31	44	58	96	36	41	31	41	80	80	119	778	685	304
	%	117	45	53	85	131	52	53	35	45	78	77	122	76	123	65
Tay	mm	128	52	75	68	124	62	74	30	52	30	160	122	978	764	410
	%	88	53	67	99	143	82	90	30	43	22	126	91	76	101	77
Forth	mm	124	46	61	54	106	65	78	28	68	44	113	115	904	638	400
	%	105	57	62	88	139	91	101	29	60	37	97	101	79	99	80
Clyde	mm	174	85	94	58	169	100	111	59	106	76	229	193	1453	837	603
	%	92	69	62	65	176	103	98	41	58	39	124	104	83	81	84
Tweed	mm	108	34	49	42	102	50	68	12	52	72	84	109	783	629	326
	%	108	48	60	69	139	74	91	14	56	73	87	113	78	115	71
Solway	mm	138	77	80	66	127	76	107	27	86	50	197	155	1187	862	488
	%	91	76	67	84	144	89	115	22	60	32	135	103	83	104	80
Western Isles; Orkney and Shetland	mm	176	72	81	36	100	83	69	58	135	91	150	168	1218	633	481
	%	121	72	68	46	144	113	80	59	98	59	98	112	89	77	88

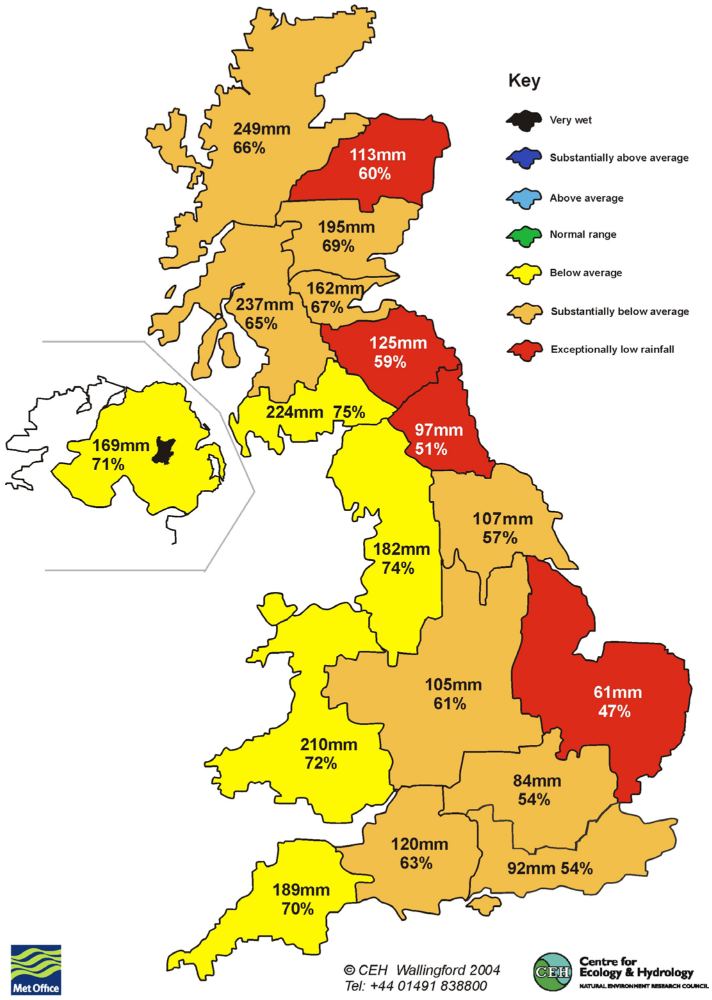


Figure 6 *February-April 2003 regional rainfall totals in mm and as a percentage of the 1961-90 average.*

Data source: UK Met Office.

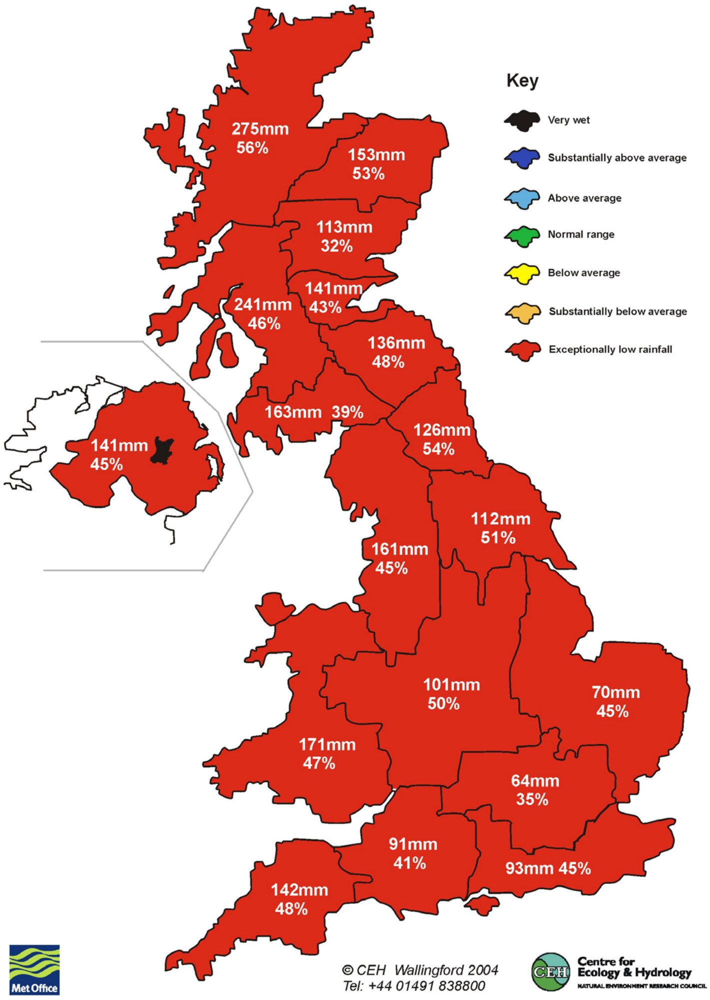


Figure 7 *August-October 2003 regional rainfall totals in mm and as a percentage of the 1961-90 average.*

Data source: UK Met Office.

return periods of around 50 years and deficiencies across almost all regions of the UK corresponded to return periods exceeding 20 years. The intensification of the drought well into the autumn resulted in the February-October period being the driest on record for the UK apart from 1921 (in a series from 1900); over this timespan, rainfall deficiencies exceeded 30% over wide areas (Figure 8). The high frequency of Atlantic frontal systems from mid-October until the end of the year was, thus, especially welcome.

Rainfall - through the year

January

January was notable for a very wide range of weather conditions – exceptionally mild interludes punctuating much colder spells with damaging blizzards on occasions. Snow constituted a significant proportion of total precipitation in parts of northern Britain (in eastern Scotland especially) and London had appreciable falls on the 8th and 30th – the latter associated with massive transport disruption. Of most hydrological significance was the continuation into January of a very wet spell during late December 2002. Some localities in central southern England reported the equivalent of 6-8 weeks of average winter rainfall over the 12 days beginning on the 21st December. Widespread rainfall on New Year's Day – Culdrose (Cornwall) reported 48mm in the 24 hours to 18:00hrs – ensured that the flooding, already notable in late December, would become more extensive and protracted. The January precipitation total was near average for the UK but much of eastern England was particularly wet, parts of East Anglia reporting almost twice the January average. However, the relative infrequency of Atlantic frontal systems after the first week resulted in generally below average January rainfall totals in the west – some catchments in Cornwall recorded <60% and longer term rainfall deficiencies – which began in the late summer of 2002 – continued to build in parts of western Scotland and the islands.

February

Weather conditions during February contrasted with those which typified most of the late autumn and early winter of 2002-03. Damaging blizzards (e.g. on the 3rd) – with substantial snow accumulations – produced considerable transport disruption in Scotland but precipitation totals were influenced more by the preponderance of dry days in mid-month; many areas reported little more than a trace of rain over the fortnight beginning on the 11th. With high pressure dominant, the rainfall total for the UK was the second lowest – for

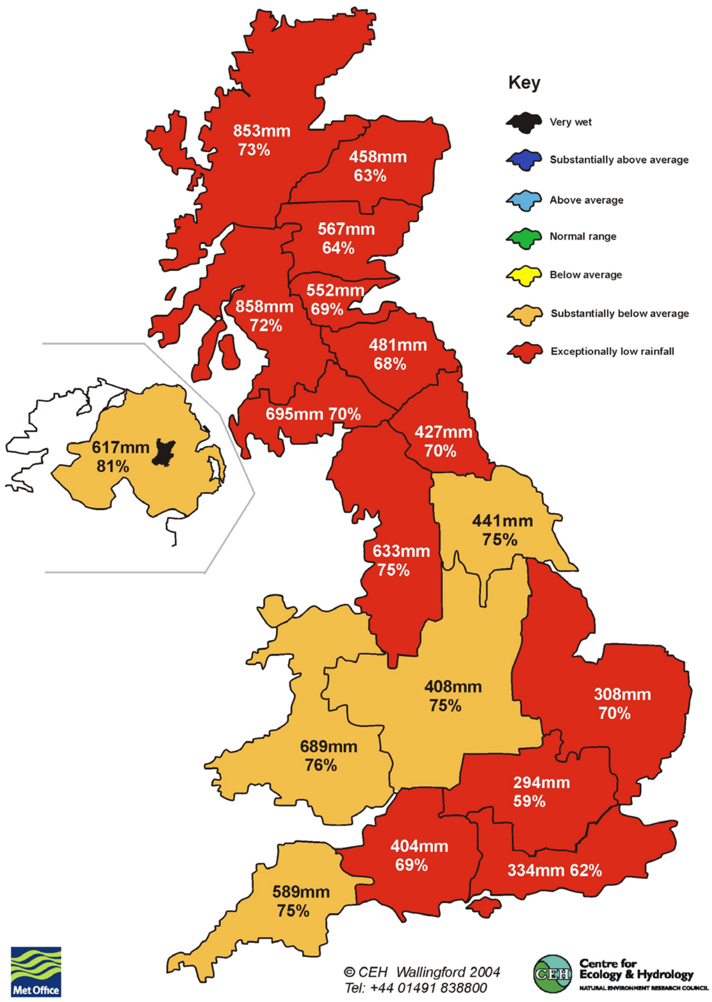


Figure 8 *February-April 2003 regional rainfall totals in mm and as a percentage of the 1961-90 average.*

Data source: UK Met Office.

February – in the last 18 years. The low frequency of rain-bearing frontal systems resulted in below average precipitation across much the greater part of the UK. A few localities (e.g. Milford Haven and Morecambe) reported marginally above average February rainfall but most catchments registered between 40% and 70%; parts of eastern Scotland were especially dry. In Scotland, a continuation of a notable longer term rainfall deficiency in the north and west contributed to the second lowest winter (December-February) rainfall total since 1964. To the south, winter rainfall totals for all regions were within the normal range, but above average rainfall again characterised much of the English lowlands – many catchments reported their fifth successive wet winter.

March

Several vigorous Atlantic frontal systems brought significant rainfall to most areas in early March – many western upland catchments reported notable falls; on the 7/8th, Capel Curig (Gwynedd) registered 111mm in 36 hrs (including 80mm in 12 hrs). However, from the middle of the second week, high pressure dominated synoptic patterns and many areas reported long sequences of days with precipitation restricted to fog-drip. In some parts of southern England (e.g. the Lambourn Valley) no rainfall was recorded over the last 24 days of the month, continuing a relatively arid interlude – extending over nine weeks in some areas – which transformed the hydrological picture across much of the UK. The parched catchment conditions (for the spring) greatly reduced the risk of flooding but also signalled an early end to the aquifer recharge season – in some eastern aquifers particularly. Rainfall totals for March were below average throughout mainland UK. Northern Ireland registered its driest March since 1973 and, in Britain, rainfall deficiencies were generally greatest in the driest regions of the country – some sheltered southern and eastern catchments reported monthly rainfall totals of less than 15mm. The combined February and March rainfall totals were the lowest for 30 years in parts of eastern Scotland, and also notably low in much of eastern England.

April

Apart from a wet and blustery start, the first three weeks of April were mainly dry, extending a dry spell which started in mid-February. Rainfall totals were especially low over the seven-week period from the 8th March. Some places in north-east England reported less than 5mm of rainfall whilst in Wallingford (Oxon), measurable rain occurred on only four days (totalling a mere 2.6mm). Fortunately, widespread frontal rainfall, beginning on the 21st, reduced the growing risk of forest fires. Nonetheless, regional rainfall totals for April were well below average across the UK – less than 50% in the Western Isles, the seaboard of north-east England, the East Midlands, central London, eastern Kent and south Dorset. Substantial rainfall deficiencies over the Febrary-April period extended across almost all regions of the UK. In this timeframe, the Northumbrian and Anglian regions reported less than 50% of average rainfall, contributing to the lowest February-April rainfall since 1976 for England and Wales, and since 1975 for Scotland.

May

The episodic weather patterns, which were a feature of much of the 2002-03 period, continued during May. Notable late-winter and spring rainfall deficiencies increased in a number of lowland catchments, but were greatly moderated in most regions as the late-April rainfall heralded a prolonged unsettled spell. Mid-May was especially wet – a daily rainfall total of 52.2mm was reported for Silent Valley (Northern Ireland) on the 15th – and the month ended dramatically with heat-wave conditions and violent thunderstorms with hailstones and localised flash flooding. An especially severe storm – with remarkable surface runoff and debris slides – afflicted Yarrowford and Selkirk (in the Tweed basin) on the 30th. This contributed to the 4th wettest May on record for Scotland in a series from 1869. By contrast, May rainfall totals in a few southern and eastern coastal areas of England fell below 70% of average and spring

(March-May) totals were particularly low throughout the English Lowlands (parts of the North-East also). In such areas, a notable drought could be traced back to mid-February; for the Thames basin the February-May rainfall was the second lowest, after 1976, in the last 48 years.

June

June was generally very warm with lengthy dry spells punctuated by showery or more stormy interludes. Rainfall for the UK as a whole was close to the long term average but its spatial variability was substantial, partly as a result of high temperatures triggering several thundery episodes. On the 1st, a 39mm rainfall total was recorded in an hour at Shepshed (Leics) and 60mm in around 2.5 hours was reported for St Leonards (East Sussex) early on the following day; both storms have return periods > 50 years. Further convective storms on the 22nd were responsible for more than half the total June rainfall in some southern catchments. More significantly, rainfall deficiencies – which had built up since late January in some areas – moderated across much of the country. Nonetheless, February-June rainfall totals were well below average in all regions; in this timeframe, many catchments in a zone from Dorset to Essex reported their second lowest rainfall total (after 1976) since 1962.

July

July was a very warm month with rainfall modestly above average for the UK as a whole but, as in June, the thundery and showery nature of much of the rainfall made for large local and regional differences in monthly totals. High intensity rainfall events were particularly common in mid-month and towards month end. A storm total of 55mm was recorded at St Athan (South Wales) on the 17th, whilst Newry (Northern Ireland) registered 70mm on the following day. On the 25th, Cardinham (Cornwall) reported 62mm and, at month-end, a remarkably intense storm produced a three-hour total of 54mm at Borgue (Dumfries and Galloway) – its estimated return period exceeds 100 years. During July, most frontal systems approached from the South-West; accordingly, a few localities in Cornwall and South Wales recorded over twice the monthly average rainfall. By contrast, areas in the rain-shadow of the western hills, (and which missed the thunderstorms), were relatively dry – parts of the west Midlands recorded <60% of the July average and some catchments along the eastern seaboard were even drier. Generally, regional rainfall totals for July were in the normal range across England and Wales but, once again, well below average across much of Scotland.

August

August was an extremely warm month – previous maximum recorded temperatures were eclipsed in many areas during a heat-wave beginning on the 3rd – and exceptionally low rainfall totals characterised most regions. Although the UK's longest absolute drought (73-days in East London in 1893) was not threatened, many notably arid interludes were reported – sequences of 26 or more rainless days being reported in parts of the English Lowlands. A few locally intense storms did occur, (e.g. a remarkable 45mm precipitation total in 10 minutes at Carlton-in-Cleveland, North Yorks on the 10th), and significant rainfall on the 28th prevented existing minimum August rainfall totals being eclipsed in many localities. Nonetheless, August totals were below 20% of average across the greater part of the UK, and less than 10% in many eastern lowland catchments. Large parts of the English Lowlands reported <5mm with only a single millimetre recorded for a few localities adjacent to the Wash. The August 2003 rainfall total was the fourth lowest for the UK in a 104-year record. More significantly, it was the seventh successive month with below average rainfall in some English lowland catchments. For the Thames basin, the February-August rainfall was the third lowest in the last 65 years – 1976 was substantially drier. Deficiencies in this timeframe were also notable in much of northern England and eastern Scotland.

September

As anticyclonic conditions continued to dominate synoptic patterns, September was another warm, sunny and, in most areas, dry month. A few notable storm events were reported – on the 19th severe damage was caused in the southern Shetlands by an exceptionally intense event and Dover suffered localised flooding on the 27th. Generally however, protracted sequences of dry days contributed to very modest September rainfall totals. Above average September rainfall was confined to a few, mostly upland, pockets whilst much of the UK registered 40-60% of the 1961-90 average with totals below 20% in substantial parts of southern England. England and Wales recorded its second driest August-September period in a series from 1766 and the extremely arid end to the summer half-year substantially increased the rainfall deficiencies that had been building since late January. The February-September rainfall total for the UK is the second lowest, after 1959, in the last 74 years – testifying to a notable and extensive drought which was most severe in parts of north-eastern Britain and the South-East. By the end of September, the estimated return periods for the post-January rainfall deficiency exceeded 20 years over the greater part of the UK.

October

Significant rainfall during the last week of October provided a welcome break in the drought conditions but rainfall deficiencies again increased considerably over the month. The UK rainfall total for the nine months ending in October 2003 was the lowest since

1921 with a few southern catchments having reported below average rainfall in each of the nine months. Thus, the abundant rainfall across parts of central southern England in the six days to the 2nd November – was particularly welcome; in some areas the 6-day total exceeded that for the preceding 12 weeks. Nonetheless, October rainfall totals were well below average across much of the UK; several monthly minima were established (e.g. Solwaybank, Dumfries and Galloway, reported its lowest October total in a 43-year record). Importantly from a resources perspective, many reservoir gathering grounds (including the Pennines) recorded below half their average October rainfall and for England and Wales as a whole, the February-October total was the second lowest, after 1959, since 1921. At month end the drought still affected much the greater part of the UK – return periods for the nine-month rainfall totals exceeded 50 years over wide areas. There were, however, important regional and local variations; an especially intense drought afflicted parts of the Thames basin – the February to October rainfall for the west London area was the second lowest in a series from 1697.

November

November was a mild month with large spatial variations in rainfall amounts. Drought severity increased across much of the Midlands and northern Britain where November rainfall was below average. By contrast, the South East was exceptionally wet. Cyclonic conditions dominated during the third week and one particularly slow-moving system generated rainfall totals of 40-80mm across a large part of the English Lowlands (Wisley in Surrey registered 95mm in 96 hrs; a few localities reported more rainfall than over the preceding three months). The, mostly moderate intensity, rainfall was very effective in reducing soil moisture deficits. Further rainfall over the following weekend contributed to November totals of twice the average in parts of the English Lowlands. Nonetheless the February-November rainfall totals for England and Wales and Scotland rank, respectively, third driest in the last 116 years and the lowest since 1955. Entering December, accumulated rainfall deficiencies exceeded 20% in most regions of the UK. The drought remained very extensive but the November rainfall changed its focus – the most severe deficiencies (over 10 months) were now in northern England and eastern Scotland.

December

Even in southern Britain, a wide range of precipitation types – from fog-drip to snow – were reported during December. However, the very damp complexion to the weather, from mid-month especially, often failed to translate into substantial daily rainfall amounts. Exceptions included a 36mm total on the Isle of Wight on the 1st and 80mm in 18 hrs at Shap Fell in the Lake District (26th); both were very useful storms in a water resources context. Despite the reduction in regional rainfall deficiencies over the latter half of the month, the February-December total for Britain was the third lowest since 1933. The drought remains notable in this timeframe – especially in the North-East where parts of Yorkshire recorded above average rainfall for only two months in 2003 (a distinction shared with parts of the Midlands and central southern England). Although the December rainfall total was only marginally above average for the UK, the nature of the mostly frontal rainfall and the generally wet soil conditions ensured that it was very hydrologically effective – contributing to a very notable improvement in the water resources outlook.

Evaporation and Soil Moisture Deficits

Background

On average, over 40% of UK rainfall is accounted for by evaporative losses – but the proportion varies greatly from region to region, reaching around 80% in the driest parts of the English Lowlands. Evaporation may occur directly from open water surfaces, from the soil or as transpiration from plants. Potential evaporation (PE) is the maximum evaporation which would occur from a continuous vegetative cover amply supplied with moisture. PE losses exhibit a strong annual cycle, peaking normally in June or July; typically, only 10-20% of the annual PE loss occurs during the October-March period. Given normal rainfall, the increasing temperatures and accelerating evaporative demands through the spring lead to a progressive drying of the soil profile and the creation of what is termed a Soil Moisture Deficit (SMD). Eventually, the ability of transpiration to proceed at the potential rate is reduced as a result of the drying soil conditions, the associated reduced capability of plants to take up water, and the measures plants take to restrict transpiration under such conditions. Thus in the absence of favourable soil moisture conditions actual evaporation (AE) rates will fall below the corresponding PE rates, appreciably so during dry summers. When plant activity and evaporation rates slacken in the autumn, rainfall wets-up the soil profile once more – allowing runoff rates to increase and infiltration to groundwater to re-commence. Knowledge of the soil moisture status and evaporation rates are essential factors in understanding water resource variability.

The following commentary on evaporation patterns and soil moisture deficits during 2003 relies, in large part, on monthly figures derived by the Met Office Rainfall and Evaporation Calculation System (MORECS)[2].

Potential and actual evaporation losses

Although marginally cooler than 2002, 2003 added a further year to an exceptionally warm cluster; the mean Central England Temperature for 2003 provisionally ranks equal 7th warmest in a series extending back to 1659[1]. During the last 16 years, only in 1996 have annual mean temperatures fallen below the 1961-90 average and, over the 1998-2003 period, the average temperature has been approximately 0.7C above the preceding mean. In 2003, only February and October were cooler than average and temperatures over the June-September period were exceptionally high; only 1826 and 1976 have been warmer in this timeframe. Evaporation losses reflect other factors as well as temperature (e.g. windspeed, humidity and land use) but large positive temperature anomalies are typically associated with high evaporative demands. Correspondingly, annual potential evaporation (PE) losses for 2003 were generally well above average across almost the whole of the UK (see Figure 9). Large areas, mostly in the English Lowlands, registered MORECS PE totals exceeding 700mm with large parts of East Anglia having totals substantially greater than the 2003 rainfall total – a situation more commonly associated with central and western France. Over much of eastern Britain, PE totals for 2003 were 15-25% above average (Figure 9) – anomalies were generally much more modest in the wetter western regions where a few upland areas registered below average annual totals.

As is normally the case, annual actual evaporation (AE) losses for 2003 displayed a narrower range than those for PE totals, but the pattern of regional anomalies was also significantly different. This reflects the impact of the extremely dry soil conditions during the summer half-year (see below). Across Britain, AE totals were mostly in the 420-600mm range with the highest annual losses in western and northern Britain (Figure 10). AE totals were especially high – approaching 20% above average – in parts of the South-West and Wales where transpiration losses were constrained for only a limited period. Conversely, transpiration losses were inhibited for four months or more in parts of the English Lowlands. This resulted in very large annual shortfalls of AE totals relative to PE totals – in some areas (e.g. the Thames basin) the shortfalls were the third highest (after 1990 and 1976) in the 43-year MORECS series.

Soil Moisture Deficits

The development and decay of soil moisture deficits over the 1998-2003 period is illustrated in Figure 11 for six representative MORECS squares; the SMD values relate to the end of each month and assume a grass cover. Monthly PE and AE totals are also shown together with the differences in the annual PE and AE totals. Generally, maximum soil moisture deficits in 2003 were more similar to those of the early and mid-1990s than the more recent past. A very notable feature of the 2003 SMD profiles is the lateness of the maximum deficits and their subsequent steep decline – which resulted in near-saturated soils throughout almost the entire country by the end of the year.

During 2003, soil moisture deficits began to build exceptionally early – becoming established in some eastern and southern areas by late February. Driven by evaporative demands more than 25-30% above average over wide areas, significant SMDs extended across most regions through March. At month-end they were the highest in the MORECS series in some (mostly western and northern) areas.

A combination of low rainfall and seasonally high evaporative demands saw further SMD increases through April and the continuation of relatively arid conditions in May resulted in deficits that, by month-end, were more typical of early August across much of eastern Britain (see Figure 12). Further dessication in June produced early July SMDs which would, typically, be expected once every 5-10 years on average. The onset of more unsettled weather patterns meant that SMD increases during July were more erratic and mid-summer deficits were mostly in the normal range, albeit still appreciably above average. SMDs again increased rapidly in August, ending the month 30-40mm above the late summer average over wide areas – and exceeding previous end-of August maxima in a few areas (e.g. parts of eastern Scotland). Deficits normally decline considerably in September but in 2003 they continued to climb. At the end of September, soil moisture levels were their lowest, or second lowest, in the MORECS series in many parts of the UK (see Figure 13); previous September maxima were eclipsed by significant margins in parts of southern England. By early October SMDs were the equivalent of 10-14 weeks of residual rainfall (rainfall-actual evaporation) across much of the English Lowlands. This raised concerns regarding the likely delay in the onset of the seasonal recovery in river flows and groundwater recharge.

Across most of the country deficits began to decline in October (from mid-month especially), but they were still very high (for the autumn) at month end in many areas. However, in most areas, the very brisk decrease in SMDs continued through November and the well distributed December rainfall ensured that by the end of 2003 areas with significant soil moisture deficits were restricted to a few low-lying eastern areas (e.g. the Vale of York, and inland from the Wash).

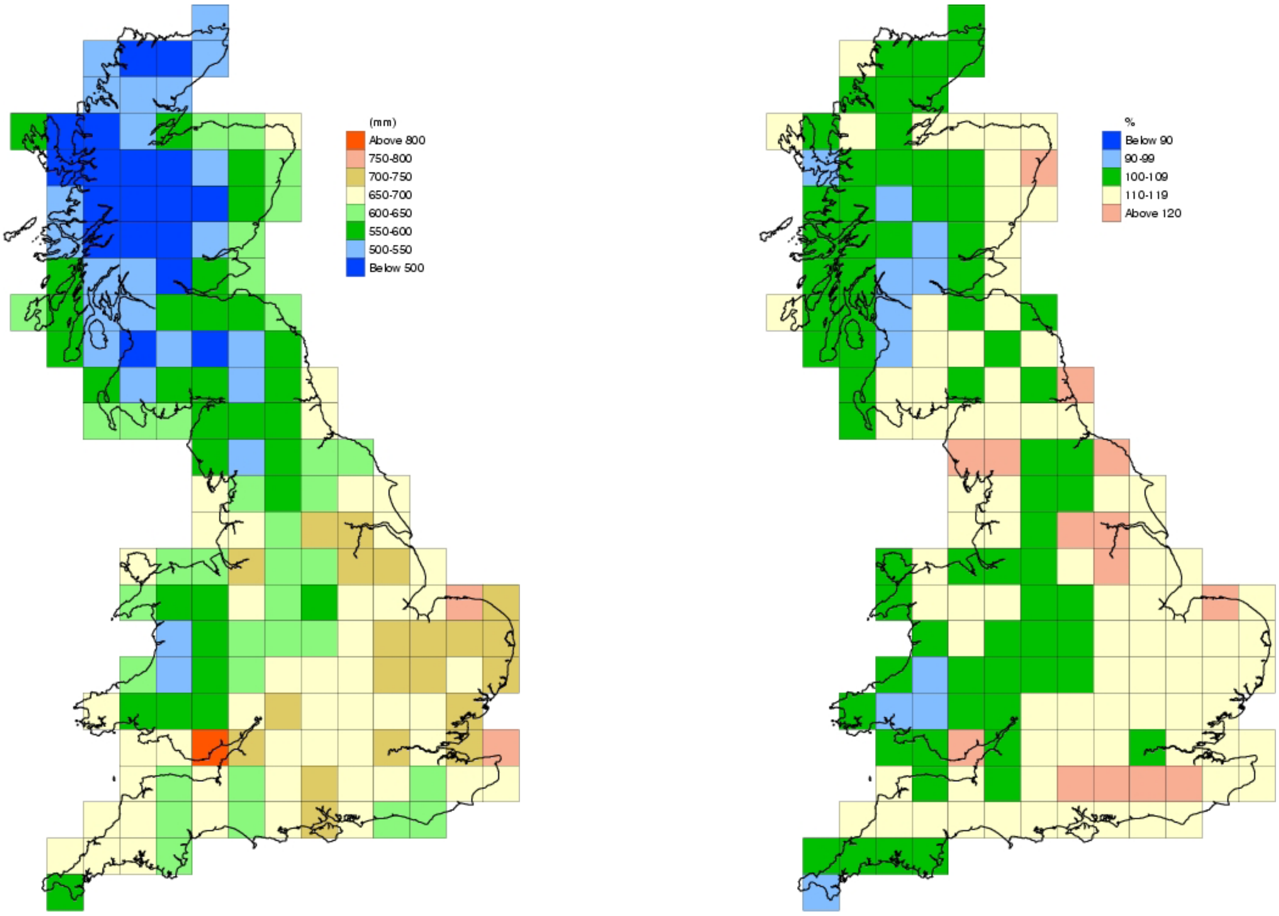


Figure 9 *Potential evaporation totals for 2003 in mm and as a percentage of the 1961-90 average.*

Data source: MORECS.

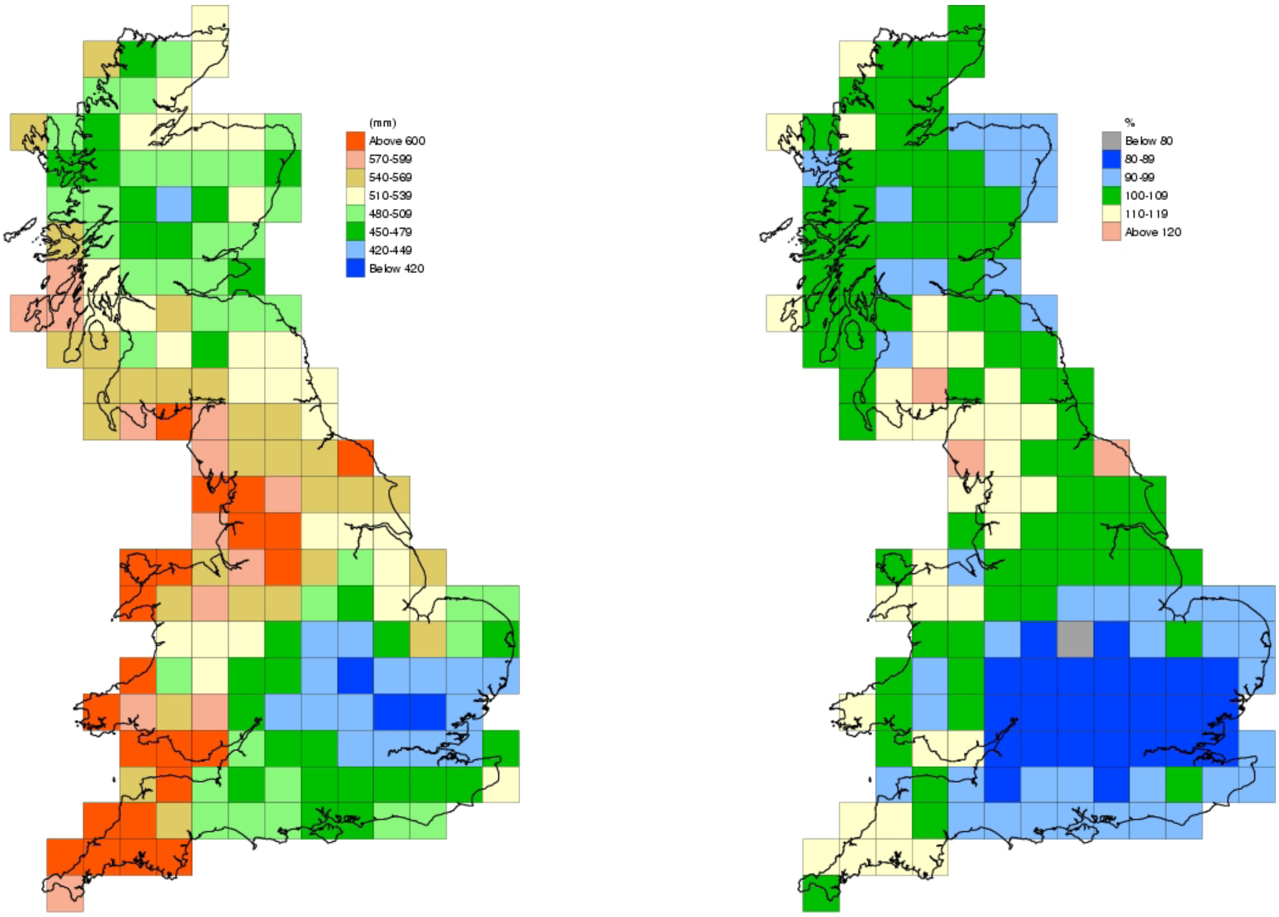


Figure 10 *Actual evaporation totals for 2003 in mm and as a percentage of the 1961-90 average.*

Data source: MORECS.

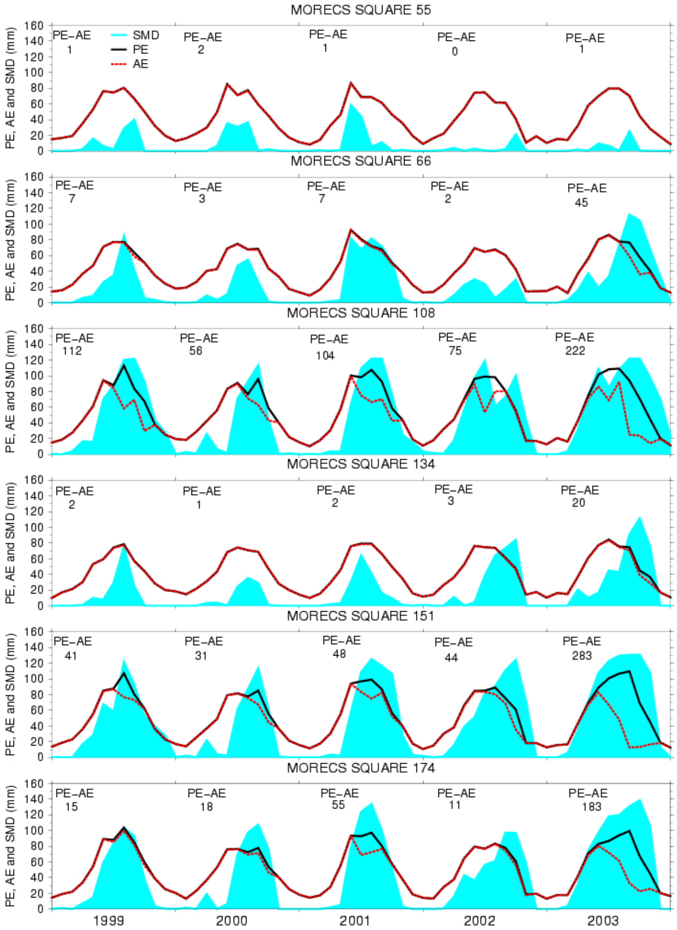


Figure 11a The variation in potential evaporation, actual evaporation and soil moisture deficits for six MORECS squares 1999-2003.

Data source: MORECS.

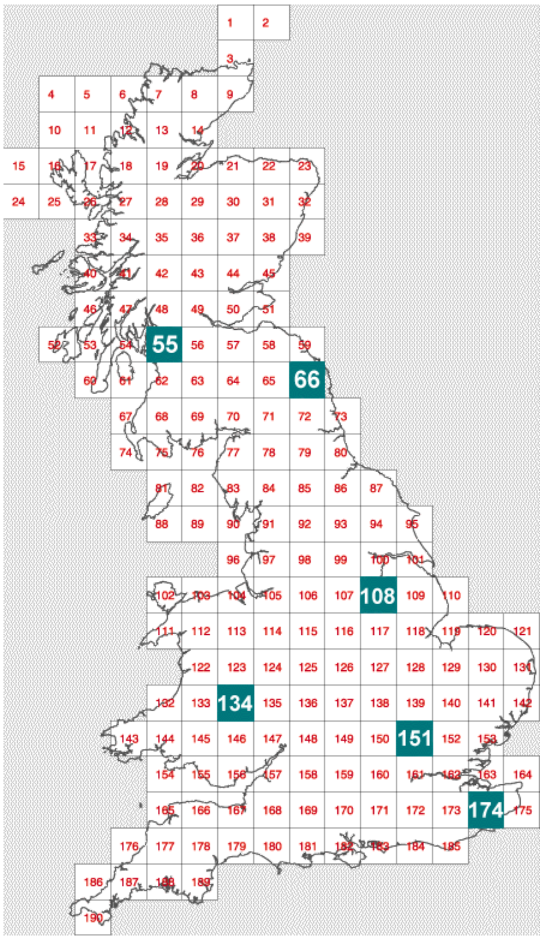


Figure 11b MORECS Location Map: the location of the 40km squares and their associated reference numbers.

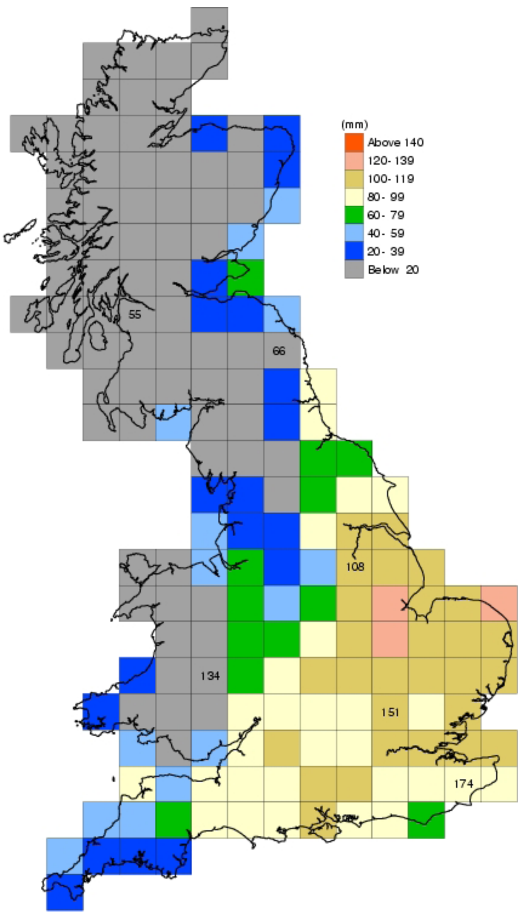


Figure 12 Soil Moisture Deficits at the end of May 2003.

Data source: MORECS.

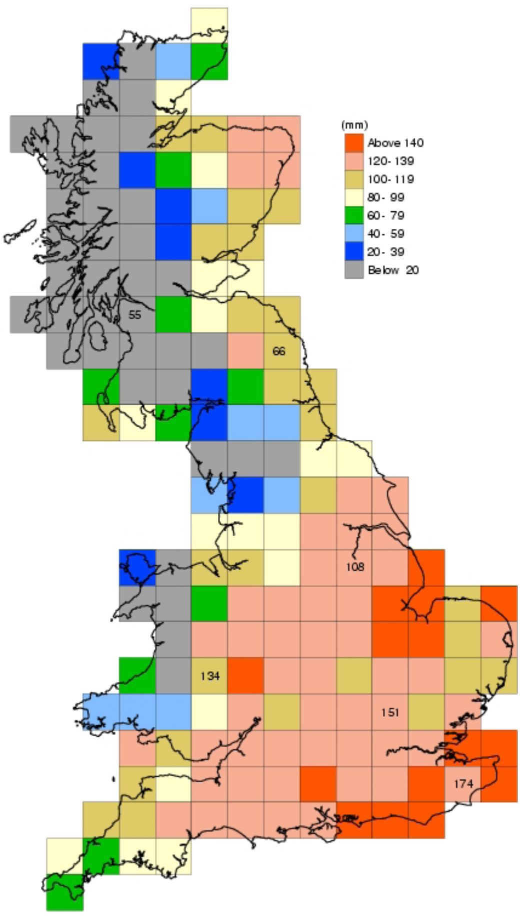


Figure 13 Soil Moisture Deficits at the end of September 2003.

Data source: MORECS.

River Flows

The year in brief

2003 was notable for the range of flows experienced in many rivers and the sustained low flows caused by the drought which affected all parts of the UK. Relative to the seasonal average, the low flows were most exceptional in the late spring and early autumn, resulting in a modest extension in the range of recorded variability for those periods in many areas – parts of Scotland particularly. New minimum accumulated runoff totals over timespans of 8-10 months were also established for many gauging stations and a significant number of existing minimum annual runoff totals were eclipsed – particularly in northern Britain. By contrast, many rivers across southern Britain registered exceptionally high flows in January with widespread flooding; existing record January runoff totals were superseded in a number of rivers sustained primarily by groundwater. Thereafter, major floodplain inundations were rare but localised, mostly urban, events were relatively frequent occurrences – often causing severe, if short-lived, transport disruption. In some responsive catchments in the English Lowlands localised flooding was common during November whilst flow recoveries were still awaited in other lowland rivers (the co-existence of ongoing drought conditions and significant flood risk is not especially rare during the late autumn).

Annual minimum river flows in recent years have generally been considerably greater than those recorded over the 1989-1997 period. Despite the drought, 2003 followed this pattern across much of the UK; minimum flows were mostly well above those registered in other drought episodes over the last 30 years – this reflected the wetness of the early summer period and, in permeable catchments, groundwater contributions which helped sustain flows throughout most of the drought period. Importantly however, new minimum daily or, more commonly, monthly flows were recorded in a modest number of responsive catchments in parts of northern and western Britain – most notably in eastern Scotland where a new minimum monthly flow (for any month) was established for the Don (in August) in a 35-year flow record. In some cases, the depressed flow rates, combined with high water temperatures, produced considerable ecological stress (e.g. salmon fatalities were reported in the Aberdeenshire Dee during August).

Figure 14 shows 1999-2003 hydrographs representing the total outflows from Great Britain, England and Wales, Scotland, and Northern Ireland – the hydrographs are based on flows for a network of large rivers which, taken together, provide a convincing guide to runoff patterns at the national scale. The hydrograph for Northern Ireland reflects, in part, the controlled flow releases from Lough Neagh into the

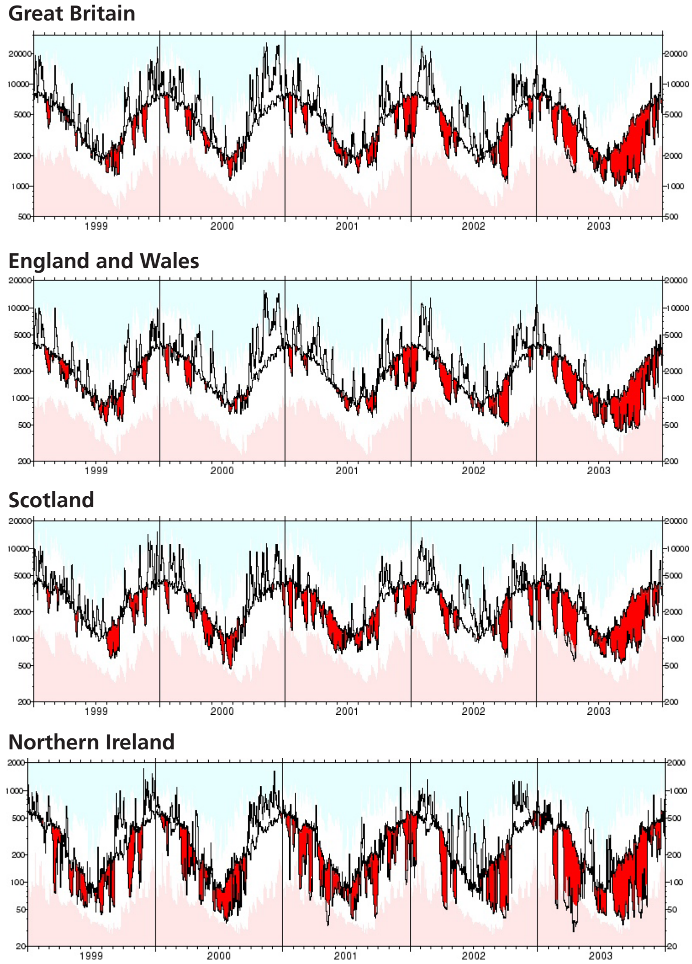
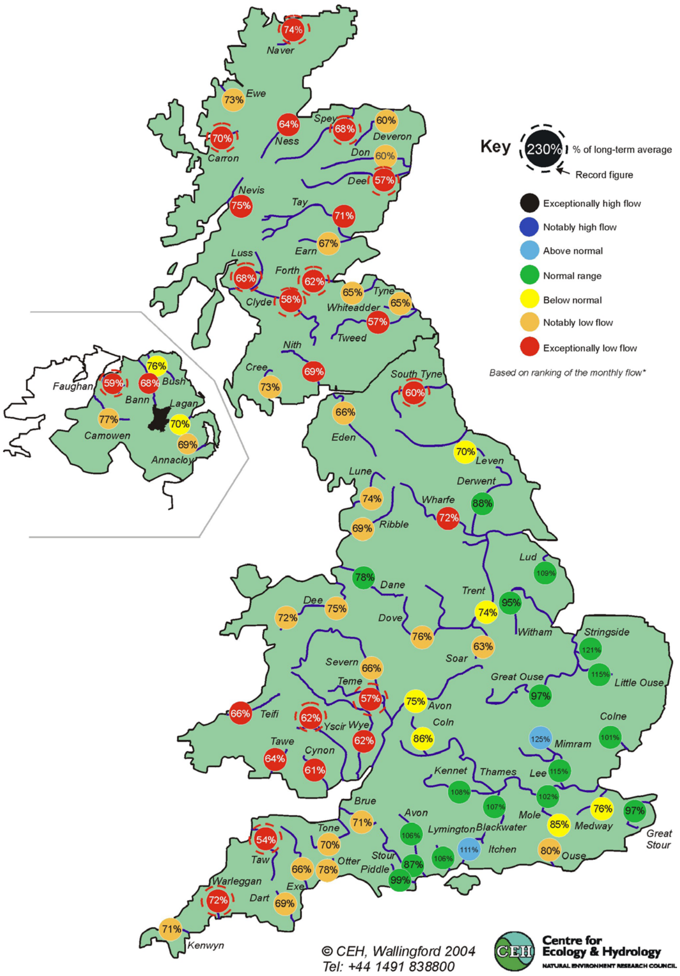


Figure 14 *A guide to total daily outflows for 2003.*

Lower Bann – these constitute more than a third of the total outflows from Northern Ireland. To emphasise the periods of low flow during 2003 a red infill is shown between the actual flow and the corresponding long term average; long term daily maximum and minimum flows are represented by the pink and blue envelopes. At the national scale, the hydrographs confirm the seasonally depressed flow rates which accompanied the most intense phases of the drought; extensions to the recorded range of daily outflows occur where the 2003 hydrograph trace overlaps the low flow envelope (see, for instance, the April outflows for Scotland and Northern Ireland).

The depressed flow rates during the drought period are reflected in Figure 15 which illustrates 2003 runoff totals (expressed as a percentage of the period-of-record average) for a network of index gauging stations throughout the UK. In much of southern and eastern England, annual runoff totals were within the normal range, and above average flows characterised a number of rivers draining permeable catchments. By contrast, flows in impermeable catchments, which predominate across northern and western regions of the UK, were notably below average – new annual minima runoff totals were established for a small proportion of index rivers (including the Spey, Yscir, Taw and, in Northern Ireland, the Faughan).



* Comparisons based on percentage flows alone can be misleading. A given percentage flow can represent extreme drought conditions in permeable catchments where flow patterns are relatively stable but be well within the normal range in impermeable catchments where the natural variation in flows is much greater.
Note: the period of record on which these percentages are based varies from station to station.

Figure 15 *2003 runoff totals as a percentage of the previous average.*

Data sources: Environment Agency/Scottish Environment Protection Agency/ Rivers Agency.

A more detailed regional breakdown of the river flow patterns in 2003 is provided by the hydrographs for 20 index gauging stations featured on Figure 16. The year began with high flows across most of southern Britain but very depressed runoff rates typified a number of rivers draining northern Scotland (see Figure 17). Common features of the 2003 river flow hydrographs are the very steep and protracted spring and autumn recessions together with the relative stability of flows throughout much of the summer half-year. Runoff rates in April and October were especially depressed relative to the monthly averages (see Figures 18 and 19). Regional rainfall patterns and contrasting catchment geology resulted in large spatial variations in the rate of seasonal river flow recoveries during the late autumn and early winter. However, flow rates across almost all of the UK were well within the normal range at the end of 2003.

In common with the preceding three years, river flow patterns in 2003 across the UK departed significantly from those experienced in a typical year. The unusual nature of flow regimes in 2003 is evident from the flow duration curves featured in Figures 20 and 21. These curves allow the proportion of time that river flows are above, or below, any given threshold to be identified – they also provide a means of comparing the regime for a particular year with that for the previous record. The 'national' duration curves (Figure 20) testify to the broad extent and persistence of drought conditions. All three curves depart substantially from the corresponding period of record traces (in blue) throughout almost the entire flow range. An important exception however is found in the lowest flow range where the flow exceeded 98% of the time is close to the long term average. This was beneficial from both a water resources and ecological perspective.

Flow duration curves for a representative network of rivers across the UK (Figure 21) mostly reflect the national picture but they also reveal significant regional departures from the general pattern. In eastern Scotland, the 95% exceedance flow was markedly below the long term average, and close to the lowest on record for some rivers (e.g. the Tweed and Dee). Conversely, rivers in western Scotland maintained relatively healthy low flows. This was also true of many spring-fed streams and rivers throughout the English Lowlands.

River flows – through the year

January

River flows displayed wide temporal variations during January which began with remarkably high flows – and extensive flooding – across much of southern Britain as many rivers exercised their natural right of dominion over their floodplains. In a few catchments – including the Thames where over 450 properties were flooded – flows were the highest since the very widespread flooding in March 1947. A number of gauging stations (e.g. in Cambridgeshire and Berkshire) reported flow rates above previous maxima – in records exceeding 30 years in some cases. Flood warnings (peaking at more than 300 on the 2nd) applied across much of the river network in southern Britain. Locally, flood risks were exacerbated by drainage problems and direct runoff from farmland; 'clearwater' flooding (the result of exceptionally high groundwater levels and spring outflows) was also reported, e.g. in the Kennet valley. However, given the antecedent rainfall and the magnitude of the peak flows, flooding of properties was relatively modest. Nonetheless, the onset of anticyclonic conditions provided a very welcome respite, heralding sustained recessions in most rivers. January runoff totals were well above average across the English Lowlands, particularly in East Anglia and the Thames basin; rivers establishing new maximum January flows included the Little Ouse and Kennet. By contrast, frozen upland catchments resulted in very low flows in many western and northern rivers during the first week and January runoff totals were appreciably below average, albeit well within the normal winter range.

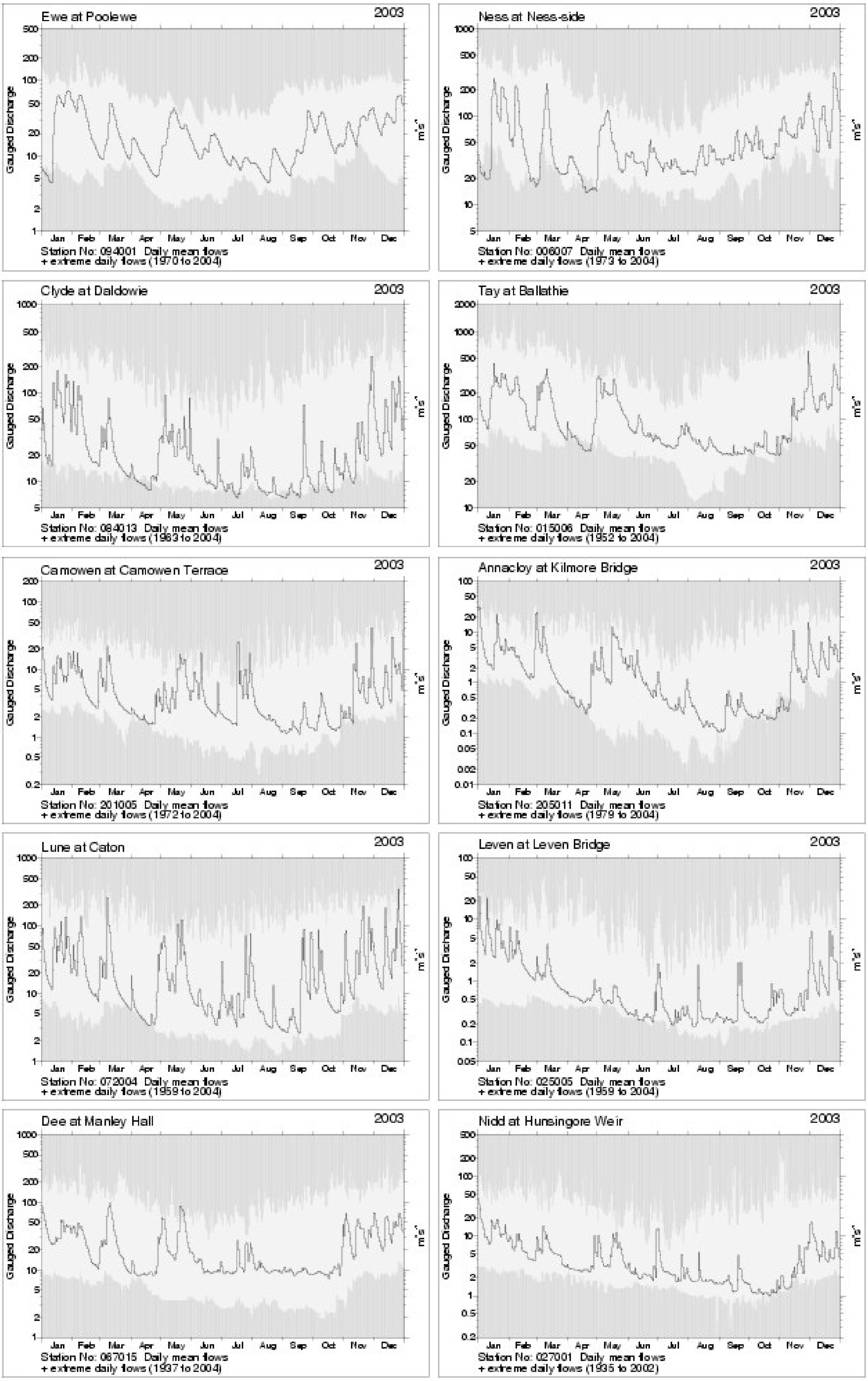


Figure 16 *Daily flow hydrographs for 2003 for a selection of index stations.*

Data sources: Environment Agency/Scottish Environment Protection Agency/Rivers Agency.

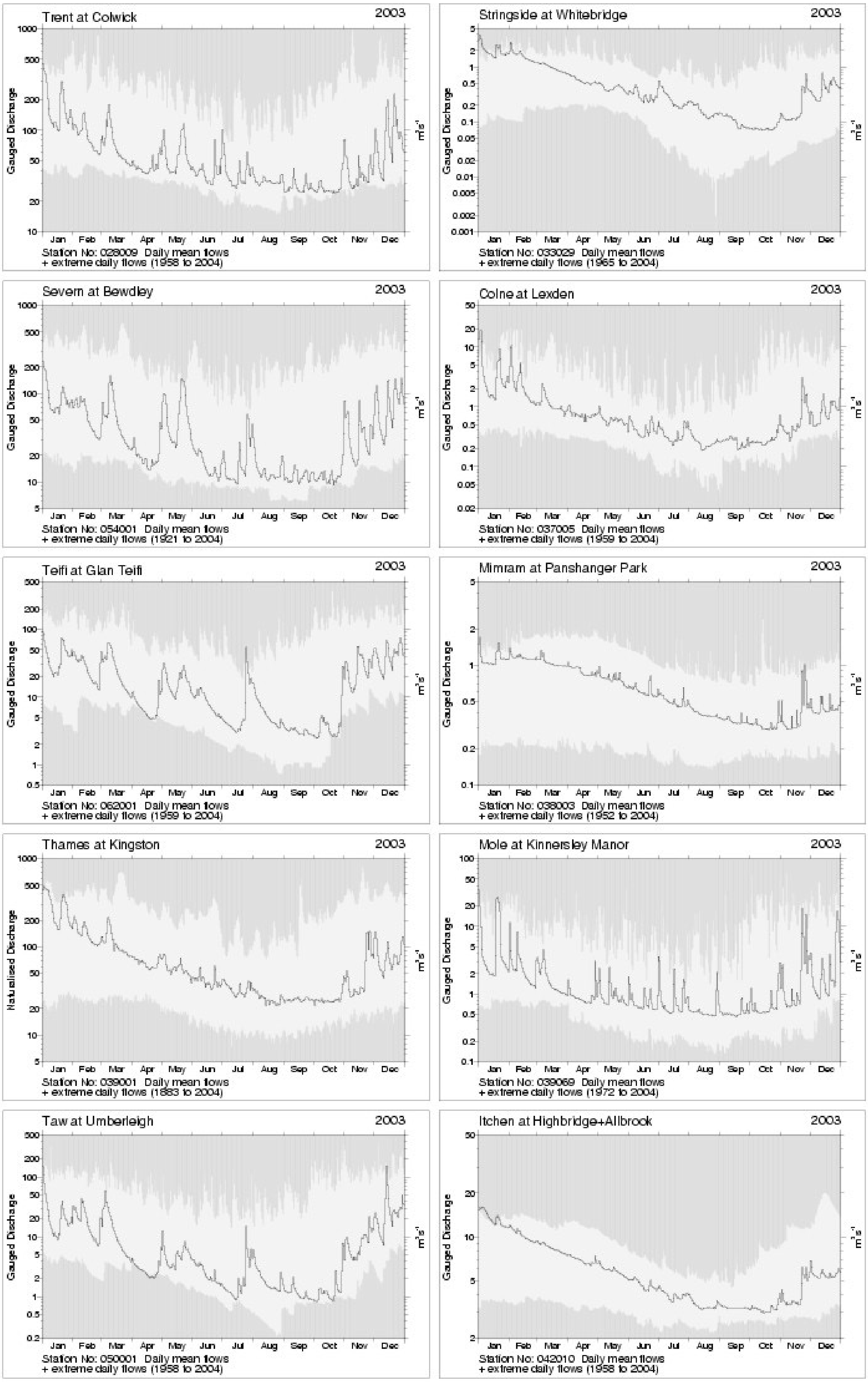
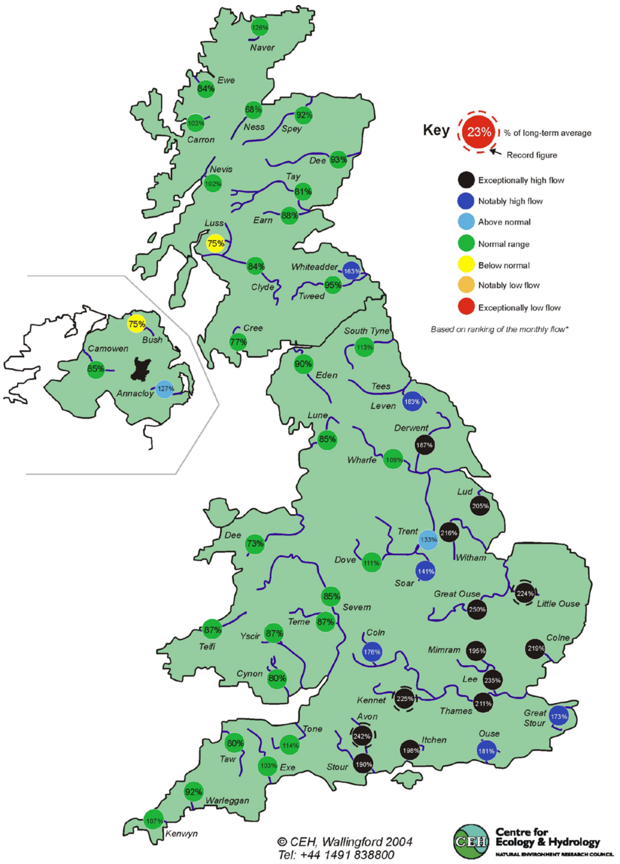


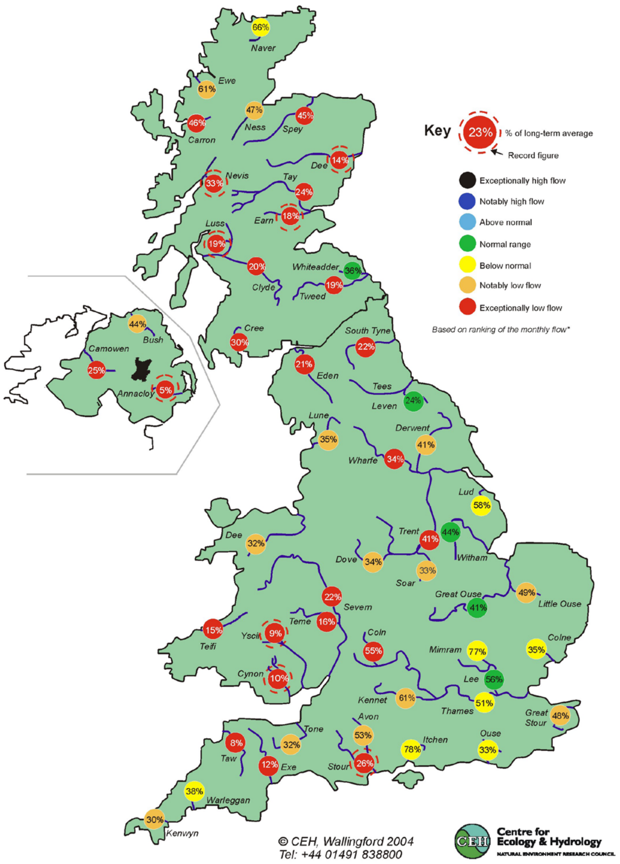
Figure 16 *(Contd.)*



*Comparisons based on percentage flows alone can be misleading. A given percentage flow can represent extreme drought conditions in permeable catchments where flow patterns are relatively stable but be well within the normal range in impermeable catchments where the natural variation in flows is much greater.
Note: the period of record on which these percentages are based varies from station to station.

Figure 17 *January 2003 runoff totals as a percentage of the previous average.*

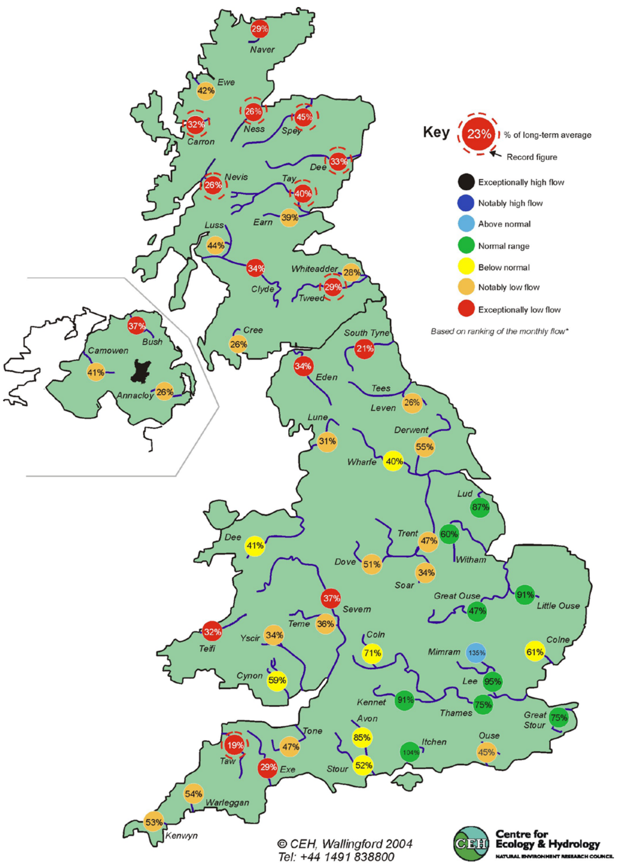
Data sources: Environment Agency/Scottish Environment Protection Agency/ Rivers Agency.



*Comparisons based on percentage flows alone can be misleading. A given percentage flow can represent extreme drought conditions in permeable catchments where flow patterns are relatively stable but be well within the normal range in impermeable catchments where the natural variation in flows is much greater.
Note: the period of record on which these percentages are based varies from station to station. Percentages may be omitted where

Figure 19 *October 2003 runoff totals as a percentage of the previous average.*

Data sources: Environment Agency/Scottish Environment Protection Agency/ Rivers Agency.



*Comparisons based on percentage flows alone can be misleading. A given percentage flow can represent extreme drought conditions in permeable catchments where flow patterns are relatively stable but be well within the normal range in impermeable catchments where the natural variation in flows is much greater.
Note: the period of record on which these percentages are based varies from station to station.

Figure 18 *April 2003 runoff totals as a percentage of the previous average.*

Data sources: Environment Agency/Scottish Environment Protection Agency/ Rivers Agency.

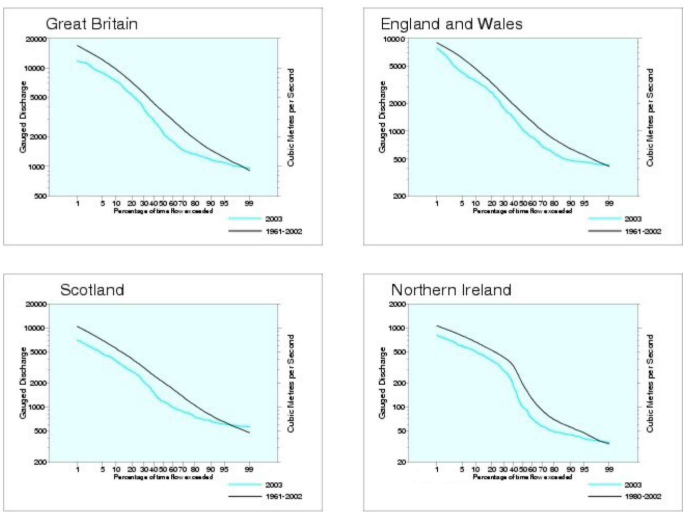


Figure 20 *Indicative flow duration curves (relating to national outflows) for 2003 (blue trace) and the preceding record.*

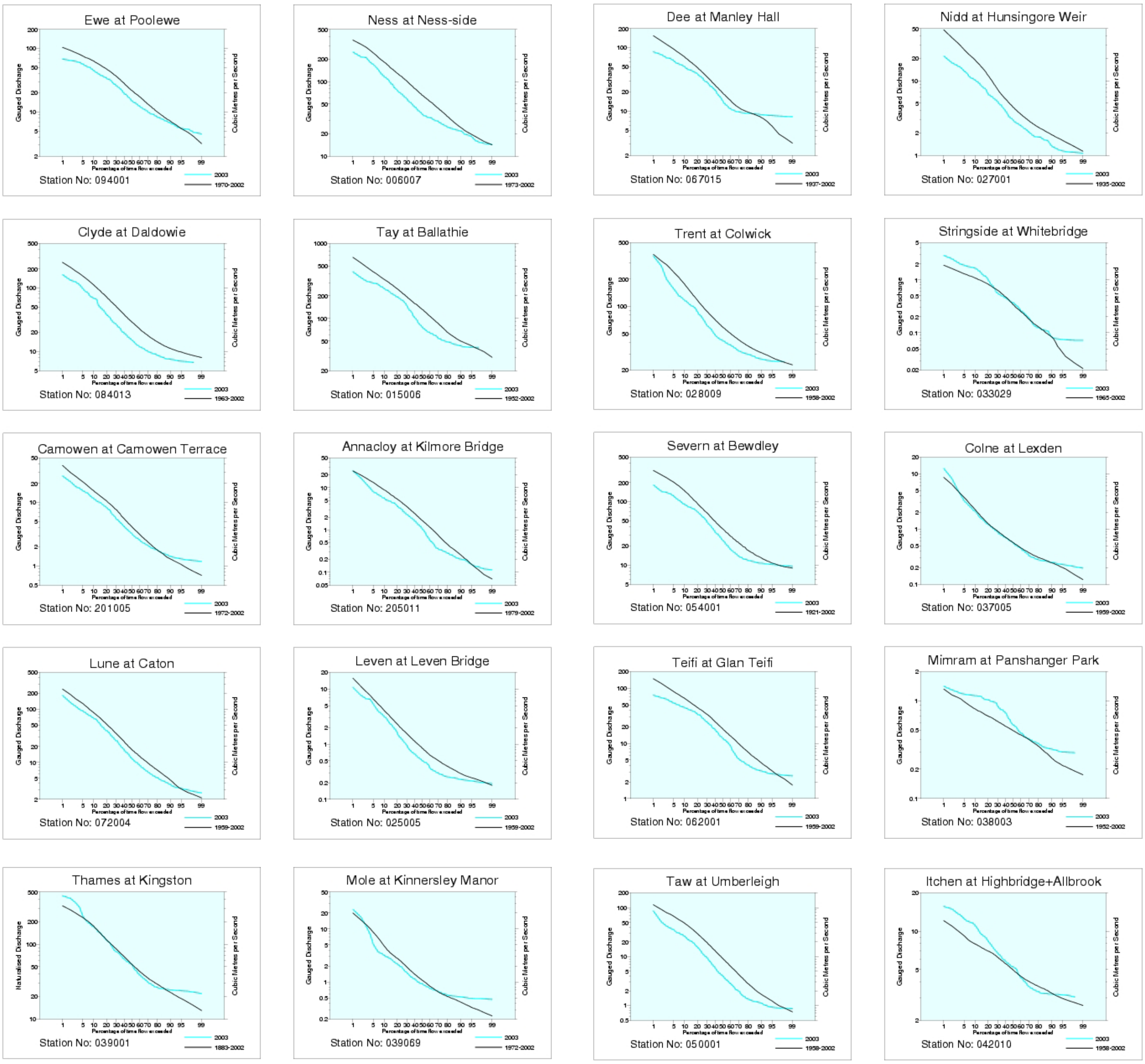


Figure 21 *Flow duration curves for 2002 (in blue) and the preceding record.*

Data sources: Environment Agency/Scottish Environment Protection Agency/Rivers Agency.

February

Across most of the country the risk of flooding declined as recessions continued through much of February before steep flow recoveries occurred around month-end in many river basins. February runoff totals displayed a clear contrast between the responsive, impermeable catchments in western and northern regions, and baseflow-dominated rivers in the English Lowlands. In the former, February mean flows were well below normal – some rivers in Scotland and Wales registered only around 50% of average runoff – whilst flows in many rivers draining permeable catchments approached seasonal maxima. Relative to the long-term average there was a strong south-east/north-west gradient in runoff for the winter (December-February) as a whole. In western Scotland the River Nevis registered its second lowest winter runoff on record, whilst the Stringside, Little Ouse (in East Anglia) and Upper Kennet (Berkshire) recorded new maximum winter runoff totals. In many more chalk streams, the winter runoff ranks second only to 2000/01.

March

Substantial storm rainfall totals in late February and early March triggered significant spates in some western catchments. In Northern Ireland, the Annacloy reported its highest March peak flow on the 1st and flood warnings were issued in Wales during the second week. Thereafter, recessions were steep and protracted in many rivers draining impermeable catchments. The

Luss and Tawe were among a significant number of index rivers where flows fell below previous late March/early April daily minima, and the Naver (in northern Scotland) registered its lowest March runoff in a 26-year record. In contrast, the continuing benefit of heavy groundwater recharge over the preceding winter kept flows in many spring-fed rivers in the English Lowlands above average. March runoff for the Mimram, for instance, was more than 50% above the monthly mean – the 30th successive month with above average flows; easily the longest such sequence in a 52-year record. Very healthy three- and six-month runoff totals in such rivers contrasted with modest accumulations in neighbouring clay catchments and, more starkly, with many rivers in north and west Scotland. Runoff for the Carron (Highland Region) over the eight months ending in March was considerably below any previous August-March total in a 24-yr record.

April

The sharp drought conditions during the spring resulted in notably low April river flows in many impermeable catchments whilst flows in rivers benefiting from natural groundwater support remained mostly above average. Such rivers aside, flow recessions had commonly persisted from early February through to the last week of April, albeit punctuated by a number of short-lived spates. In relation to low flows, the worst affected rivers were in northern Britain; gauging stations recording new April runoff minima displayed a wide distribution (including stations on the Ness, Tay, Tweed, and Carron). New daily minimum flows for April were also common – being reported from the Taw to the Nevis. In most western and northern catchments, the protracted recessions were smartly reversed following substantial rainfall around month-end but, due to the seasonally high soil moisture deficits, the rainfall was too late to be hydrologically effective in much of the English Lowlands.

May

May began with spate conditions characterising many responsive catchments and relatively high late-spring runoff continued throughout much of the month in Scotland and Northern Ireland. At the same time, flows in groundwater-fed rivers across the English Lowlands were also healthy but, by month-end, flows were substantially below average in many impermeable English catchments. The Warwickshire Avon reported its second lowest May daily flow since 1992 and May runoff totals fell below 60% of average for a number of index rivers. By contrast, runoff in many Scottish rivers was well above average – the second highest for May in a 21-year record for the Nevis, terminating a protracted low runoff episode in the Highlands. May runoff totals were high also in Northern Ireland and North Wales – the Welsh Dee reported its second highest May runoff since 1969. With the exception of some groundwater-fed rivers, spring (March-May) runoff totals were significantly below average, notably so in north-eastern England. Over the 12 months to the end of May however, most runoff accumulations were well within the normal range (northern Scotland excepted).

June

Away from north-west Scotland (where modest spates were common) protracted seasonal recessions continued in most rivers throughout much of June. Fluvial flood risk remained low but thunderstorms generated short-lived and very localised events some of which overwhelmed drainage networks causing significant flooding (e.g. at St Leonards, East Sussex where around 30 properties were flooded on the 2nd) and considerable transport disruption. These minor spates, and continuing baseflow support in permeable catchments, helped to keep river flows above drought minima in the great majority of catchments. In many responsive catchments however, flows were well below the June average by month end – the lowest since 1996 in a number of English catchments – triggering flow augmentation measures in some areas (e.g. in Dorset and Essex). June runoff totals, whilst generally in the normal range, displayed substantial spatial variability. Healthy June runoff totals typified catchments in north-western Britain and parts of Northern Ireland but, in other impermeable catchments, June runoff was generally well below the monthly average and notably low in a few areas. In the West Midlands a new daily minimum flow was recorded on the upper Stour (on the 16th) and in eastern Scotland, the Don (at Haughton) registered its lowest June runoff in a series from 1969. The sustained recessions are reflected in depressed February-June runoff totals: the South Tyne and Spey (at Boat of Garten) reported new minima in this timeframe and totals for many rivers were in the lowest quartile.

July

The first half of July saw further seasonal recessions in most catchments with relatively depressed flows characterising many rivers draining impermeable catchments late in the second week. Thereafter, spates generated steep but short-lived flow recoveries away from the English Lowlands (and northern Scotland). Notably high late-summer flows were reported for some western and northern catchments; localised urban flooding was also common. July runoff totals were depressed across northern Britain – commonly the lowest for any month since August 1995 – but in Northern Ireland, the Camowen reported its 2nd highest July flow and in the south of the UK most July totals were in the normal range. The unusual persistence of modest flow rates in Scotland was confirmed by the August 2002-July 2003 runoff accumulations. New minimum 12-month totals (for any start month) were established in a few catchments (e.g. the Carron). After an unprecedented sequence of above average monthly runoff totals, flows in many spring-fed streams in eastern England (including the Mimram) had fallen close to the late summer mean.

August

Some increases in river flow occurred in western catchments towards the end of August but generally the summer recessions continued and, with natural storage greatly depleted in permeable catchments, runoff rates were generally depressed during the second half of the month. Daily flows were commonly the lowest since the 1995/96 drought and new absolute minimum flows were established for a few rivers draining impermeable catchments e.g. the Livet (in the Spey basin) and the Callan in Northern Ireland. Abstraction restrictions and other flow support measures were activated to mitigate low flows but, more generally, the benefit of baseflows to lowland rivers was underlined in many spring-fed rivers where flows remained in the normal range, albeit appreciably below average. August runoff totals were particularly depressed across much of northern Britain – the Deveron registered its 2nd lowest August flow in a 42-year record. Flows were also very low in some impermeable southern catchments, but generally well above drought minima. This was broadly true for the summer (Jun-August) runoff totals also but the Spey, Dee and Whiteadder were among a small minority of rivers establishing new summer minimum runoff totals.

September

Many recent droughts (including 1995, 1984 and 1976) have seen significant flow recoveries in the early autumn. Given the parched condition of most catchments in September 2003, a repetition seemed very unlikely and notably low flows were expected to become very widespread in the early autumn. Aside from rivers fed by localised storm runoff and a few lowland rivers reliant on groundwater (e.g. the Ver in Bucks), flows were very depressed throughout the month. The Tweed, Whiteadder, South Tyne, Exe and Yscir were among a number of rivers where flows approached, or eclipsed, previous September daily minima. Despite a modest flow recovery over the latter half of the month in northern Britain, monthly runoff totals were also very depressed especially in impermeable catchments. Index gauging stations establishing new September minimum runoff totals showed a very wide distribution – from the Aberdeenshire Dee (at the Park gauging station) to the Exe. Evidence of the dramatic hydrological transformation since the floods of January 2003 was provided by the February-Sept runoff totals. These were mostly in the lowest quartile with new minima common – the Spey and South Tyne closely approached 8-month minima for any start month. The exceptional early autumn soil moisture deficits, together with declining groundwater levels (and the associated drying-up of high level springs) foreshadowed further low flows in baseflow-fed rivers later in the autumn.

October

With the drought entering its most severe phase, the extended seasonal river flow recessions continued through the first half of October. River flows declined below previous late-October minima in some rivers (e.g. the Tawe, Tay and Luss Water). Short-lived spates at month end provided some relief but October runoff totals were depressed across much of the UK. Rivers draining impermeable western and northern catchments were characterised by exceptional low October mean flows – the lowest since 1972 in much of northern Britain and Northern Ireland. Runoff totals were below 30% of average in many basins and, as in September, rivers registering new monthly runoff minima showed a very wide distribution (from the Dorset Stour to the Nevis in western Scotland) and the Churn (at Cirencester) was effectively dry for the first time in a 24-year record. A longer historical perspective is provided by the Severn where only in 1947 was the October flow lower (in an 83-year record). A measure of the hydrological severity of the drought in northern Britain is provided by the June-October runoff for the Aberdeenshire Dee which, remarkably, was the lowest for any 5-month sequence in a series from 1929. Generally the 5-month runoff totals were close to long term minima in impermeable catchments across much of the country. Flows were less severely depressed in the English Lowlands where some residual benefit of groundwater support could still be recognised.

November

Despite some moderate spates triggered by late-October rainfall, mid-November daily flows were depressed across most of the UK. Period-of-record minimum flows for November were closely approached in many rivers, and eclipsed in a few (including the Tay, in a 52-year record). Thereafter, recoveries were evident in most catchments – but their magnitude varied greatly. In the South-East, the Mimram peaked at its highest November flow; localised flooding and Flood Watches were common across the English Lowlands. Notable spates were more widespread in Scotland where the Cree registered a new November maximum flow on the 29th. Despite this very welcome upturn, November runoff totals were substantially below average in almost all index catchments. The Teme reported a new minimum runoff for November and some index rivers (including the Tone and Trent) reported their 9th successive month with below average runoff. The drought's hydrological severity (and the associated decline in water resources) is well captured in the runoff accumulations for the Jan-Nov period: the Spey, South Tyne, Exe and Yscir are amongst those river establishing new minimum 10-month runoff totals for any start month. Fortunately, the brisk recovery in flows during the late-autumn signalled that the 2003 drought had entered its terminal phase.

December

In most regions, river flows continued to recover, albeit erratically, through December and, approaching year-end, flood risk was increasing rapidly in some areas. On the 24th the Lochy recorded its second highest flow in a 26-year record (having recorded new daily minima for March, April and October earlier in the year). Nonetheless, the Naver was the only index river to register an above average December mean flow. Generally, runoff totals were between 50-80% of average – mostly well within the normal range and considerably greater than drought minima (for December). The water resources stress evident over the late summer and autumn was principally a reflection of the modest runoff since January 2003. This is emphasised by the runoff deficiencies for the Feb-Dec period which, for impermeable catchments, commonly exceeded 40%. Index gauging stations establishing new period-of-record minima over this timespan once again showed a wide distribution – including the Aberdeenshire Dee (in a 74-yr record), the Taw and, in Northern Ireland, the Annacloy. The importance of groundwater to river flows, in the English Lowlands especially, is emphasised by the above average runoff over the same period for a number of spring-fed streams (including the Mimram and Itchen). Baseflow contributions had generally declined greatly by early December but, with groundwater levels rising briskly, river flow recoveries were set to continue in early 2004.

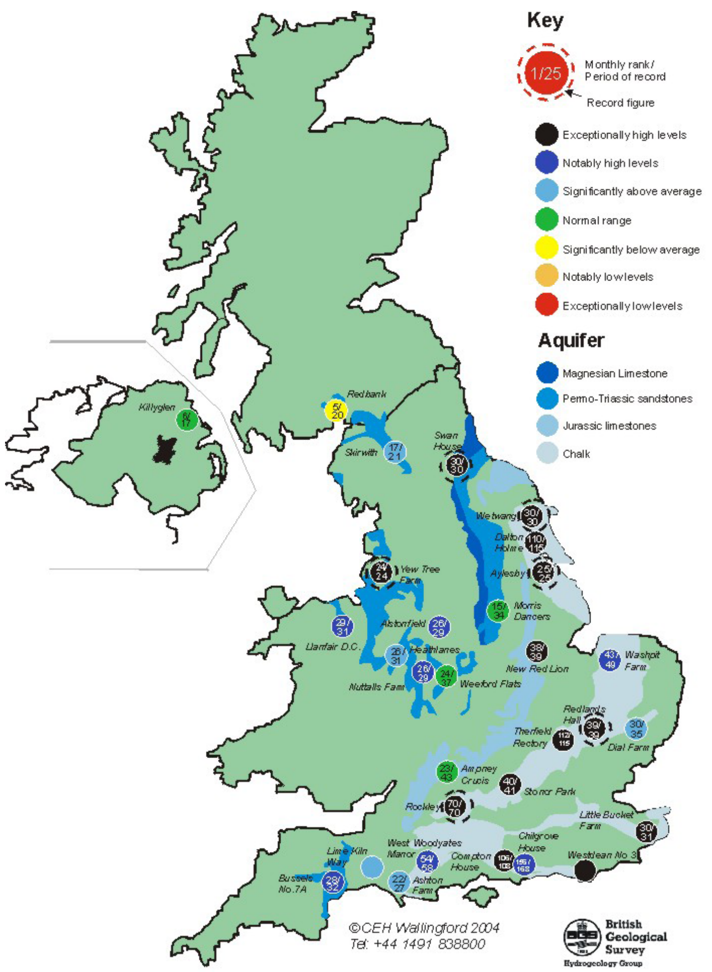
Groundwater

The year in brief

Rainfall over the outcrop areas of most major aquifers during 2003 was 15-20% below the 1961-90 average and very unevenly distributed through the year; typically, around 45% of the annual total fell in January, November and December. Thus, the most abundant rainfall occurred during that part of the year when groundwater replenishment is normally at a maximum. This, combined with the very healthy state of groundwater resources following exceptional replenishment late in 2002, meant that the drought conditions which obtained throughout much of 2003 year had only a limited impact on groundwater resources. A similar annual rainfall total across the major aquifer outcrop areas but with the bulk of the rainfall during the summer half-year would have had a much more damaging impact on groundwater resources – and on the streams supported by the outflows from springs and seepages.

Throughout much of the Chalk, the majority of the limestone aquifers, and the most responsive of the Permo-Triassic sandstones outcrops, the 2002 seasonal recovery in groundwater levels began from a lower base than in any of the previous five years – although only in a few areas (e.g. parts of the southern Chalk) did it approach drought minima. This, together with the delay in the seasonal onset of infiltration in the autumn (a consequence of the dry late summer soil conditions in 2002) suggested that groundwater levels might be appreciably below average at the beginning of 2003. In the event, exceptional rainfall over a period spanning the second week of October to mid-November, rapidly reduced soil moisture deficits and initiated a period of very heavy infiltration which continued until early January 2003. As a consequence, groundwater levels throughout most major aquifers were notably high – and still increasing – at the start of 2003 (see Figure 22).

The behaviour of groundwater levels throughout the year is shown in Figure 23 which features 1999-2003 hydrographs for a selection of index wells and boreholes throughout the UK. Five-year plots have been used because groundwater levels in many areas show considerable persistence – reflecting groundwater



The rankings are based on a comparison between the average level in the featured month (but often only single readings are available) and the average levels in each corresponding month on record. They need to be interpreted with caution especially when groundwater levels are changing rapidly or when comparing wells with very different periods of record. Rankings may be omitted where they are considered misleading. (Note: Redbank is affected by groundwater abstraction, replaced by Newbridge in 2004.)

Figure 22 *The ranking of January 2003 groundwater levels for a selection of observational wells and boreholes.*

Data sources: Environment Agency/Scottish Environment Protection Agency/ Rivers Agency.

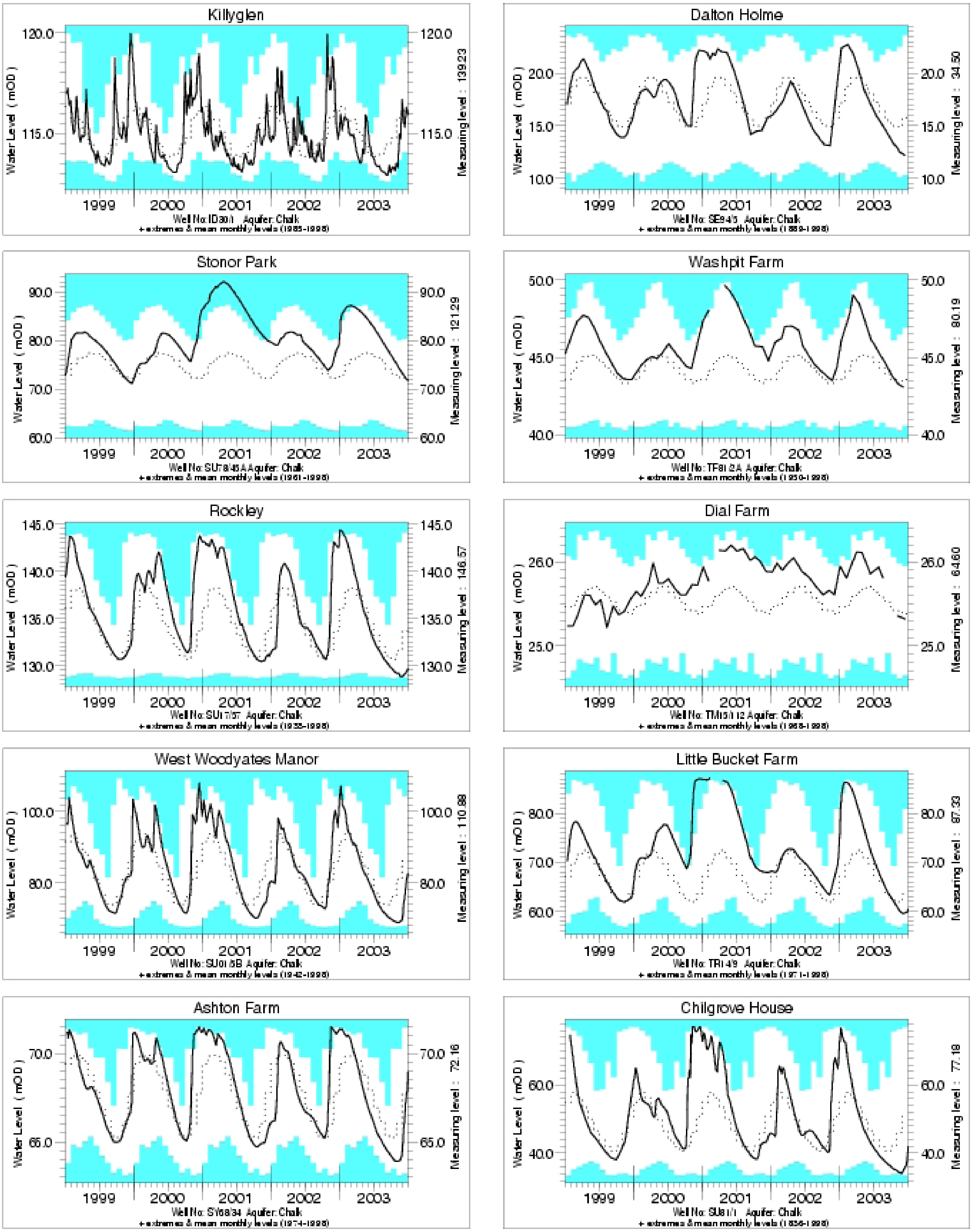


Figure 23 *Groundwater level hydrographs 1999-2003.*

Data sources: Environment Agency/Scottish Environment Protection Agency/Rivers Agency.

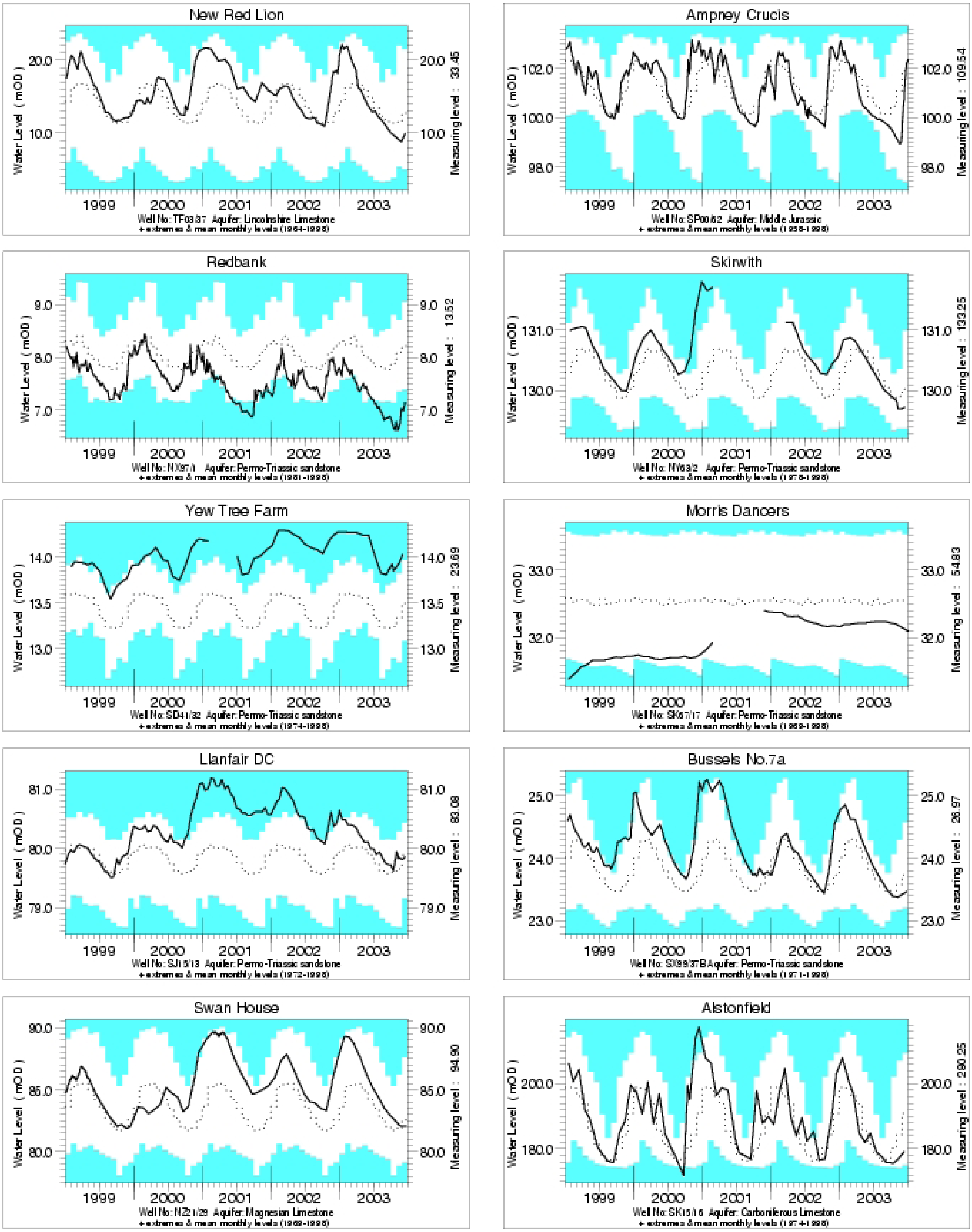


Figure 23 (Contd.)

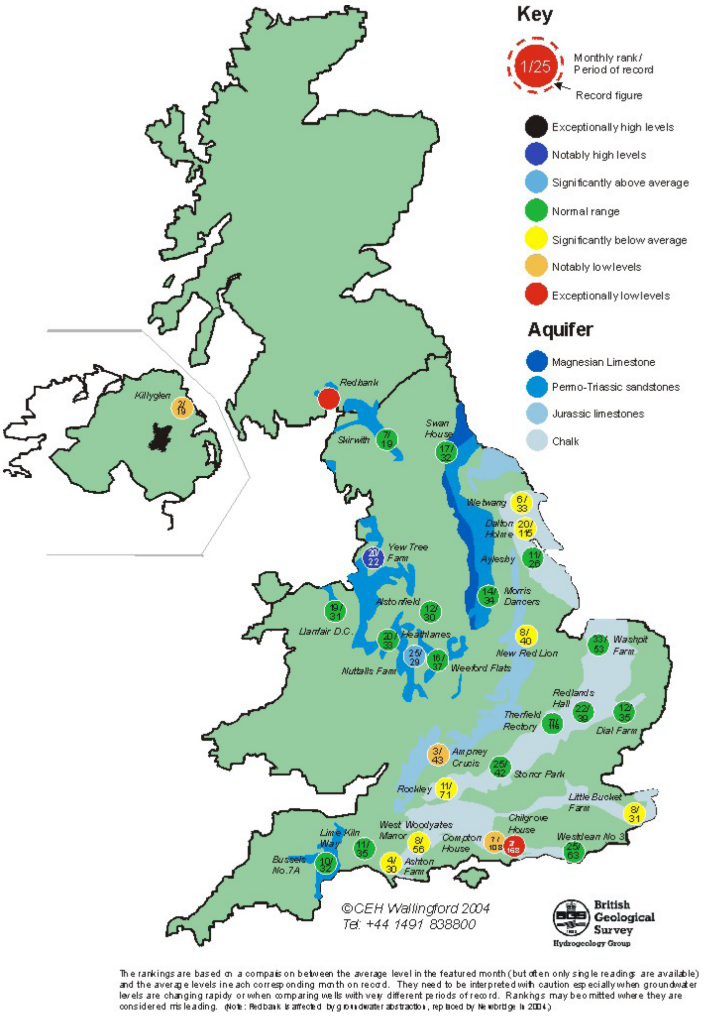


Figure 24 *The ranking of October 2003 groundwater levels for a selection of observational wells and boreholdes.*

Data sources: Environment Agency/Scottish Environment Protection Agency/ Rivers Agency.

replenishment over a number of recharge seasons. The groundwater level trace is shown together with the monthly maximum and minimum levels for the pre-1999 record. For 2003, the hydrographs suggest a near-normal seasonal variation in levels for a few index wells and boreholes. Most however are characterized by unusually protracted recessions and a very large range of levels over the year – exceeding 40 metres in the case of the Chilgrove well in the South Downs. The nine- or ten-month recessions testify to the existence of drought conditions but, a few index sites aside, the annual minimum levels in 2003 were unexceptional. This reflects the limited vulnerability of most aquifer units to drought episodes that are confined to a single year. Although the groundwater resources outlook was a matter of some concern in September and October (see Figure 24), the heavy late autumn and early winter rainfall in 2003 initiated a recovery which continued well into the following year. By late January 2004, overall groundwater resources were well above average.

The majority of observation wells and boreholes for which data are held on the National Groundwater Level Archive monitor the natural variation in levels.

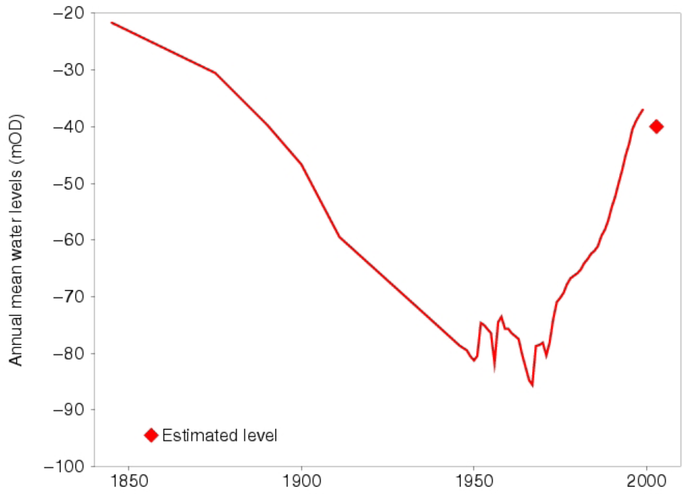


Figure 25 *Annual mean groundwater levels for the Trafalgar Square borehole.*

Data source: Environment Agency

However, in parts of the UK groundwater levels have been influenced, sometimes over very long periods, by pumping for water supply or other purposes. As a consequence, some local or regional water-tables have become substantially depressed. For instance, contemporary levels at a number of boreholes in the Permo-Triassic sandstones of the Midlands are indicative of a significant regional decline. In London, increasing groundwater abstraction through the nineteenth and the first half of the twentieth centuries led to a 70-metre decline in groundwater levels in the Trafalgar Square borehole. Since the 1950s, a much reduced abstraction rate has resulted in a recovery of around 30 metres with levels rising by 1-2 metres a year through the early 1990s (Figure 25). Level data for the 1998-2002 period are under review but the 2003 data confirm that control measures (principally abstraction by Thames Water) instigated in the late 1990s have reversed the increase – other wells in central London confirm a decline in levels since around 1999. Rising groundwater levels have also been reported from other conurbations; leakage from water mains is considered a significant factor in some cases. The implications of rising groundwater levels extend beyond the potential improvement in water resources that the rise represents. Groundwater quality may be adversely affected as levels approach the surface and a number of geotechnical problems may result, for instance the flooding of tunnels and foundations.

Groundwater levels – through the year

January

Groundwater levels approached seasonal maxima throughout many major aquifer units in January 2003. Echoing conditions in early 2001, groundwater flooding was experienced in some Chalk outcrop areas. With catchments saturated and rainfall broadly favouring the eastern outcrop areas (for the seventh successive month in some localities), January infiltration totals exceeded the average throughout most major aquifers. Infiltration over the four months beginning in September 2002 was more notable, exceeding twice the average throughout a significant proportion of the eastern Chalk (e.g. in parts of the North Downs and Chilterns). Only in 2000/01 has there been an appreciably more abundant autumn/early winter groundwater replenishment over the post-1960 period. The impact of these two exceptional recharge episodes is evident in the groundwater level hydrographs (Figure 23). January 2003 levels in most Chalk outcrop areas were unprecedented in a few areas (e.g. parts of the Yorkshire Wolds and at Rockley). Levels were notably high in most of the (more responsive) limestone outcrops and still exceeded pre-2000 maxima in a few parts of the slower-responding Permo-Triassic sandstones (e.g. at Llanfair DC).

February

February rainfall totals were below 50% of the monthly average across large parts of the Chalk outcrop and a dry, mild spell in mid-month saw modest soil moisture deficits established in some eastern and southern areas. Infiltration rates for February were typically only 25-50% of average, helping to avoid a repeat of the protracted groundwater flooding which occurred in early 2001. Significant declines in groundwater levels were reported for a number of the more responsive Chalk wells and boreholes (e.g. at Chilgrove and Rockley); nonetheless, levels generally remained notably high (Killyglen in Northern Ireland was an exception). In many slower-responding wells (e.g. Therfield), levels were still rising and exceeded pre-2000 February maxima in some areas, including the Chilterns; correspondingly spring outflows were notably heavy. Groundwater levels in the Middle Jurassic limestone of the Cotswolds fell to within the normal late-winter range but in most limestone outcrops, late-winter levels were close to seasonal maxima. Spatial variability was considerable across the Permo-Triassic sandstone outcrops but, aside from wells affected by abstraction, levels remained high – exceptionally so for some index wells in North Wales, the North-West and the Midlands.

March

Infiltration in March was again modest – less than 30% of the monthly average in some eastern aquifer outcrop areas. However, as is often the case in the spring, the differing responsiveness of individual aquifer units presented (seemingly) conflicting signals. In the Chalk, steep late winter/early spring declines in groundwater levels at some index boreholes (e.g. West Woodyates and Rockley) contrasted with continuing recoveries in some of the deeper eastern wells. Despite the paucity of late-winter/early-spring recharge, groundwater levels remained above average throughout most of the Chalk aquifer. Brisk recessions in most limestone aquifers left late-spring groundwater levels close to the seasonal average. As a consequence of the high storage capacity in many outcrop areas, levels in many Permo-Triassic sandstones outcrops reflect recharge patterns over several years. Consequently, March levels remained very high in most northern outcrops and in the Midlands. Overall groundwater resources for England and Wales also remained healthy at month end.

April

In April, a combination of low rainfall, high evaporative demand and correspondingly high soil moisture deficits terminated the recharge season in many aquifer outcrop areas – particularly those in eastern England. The spring groundwater level recessions continued, but varied greatly in their steepness. The slower responding Chalk wells (e.g. in parts of the Chilterns) were still exhibiting water levels close to their 2002/03 maxima, whilst in the far west of the Chalk outcrop some wells showed appreciably more depressed levels. The Chalk in Northern Ireland showed the greatest apparent diminution in storage – partly a consequence of the shortness of the Killyglen record (19 years). The Permo-Triassic sandstones also did not present a spatially coherent picture. Wells in the West Midlands and Lancashire reported levels well above average – some were close to the maximum recorded – whereas in the Eden valley (Cumbria), Devon, North Wales and Nottinghamshire, levels were within the normal April range. The status of groundwater resources in late April was generally satisfactory.

May

Seasonally very high soil moisture deficits throughout May confirmed the end of the 2002-03 recharge season across almost all outcrop areas of the major aquifers. Infiltration during the month was minimal (thunderstorms produced some very localised infiltration) and the drought conditions throughout much of the spring resulted in March-May recharge totals of less than a quarter of the long term average across much of the eastern Chalk. May groundwater levels contrasted sharply with those at the beginning of the year but, although groundwater levels were relatively depressed in the south-western outcrops, levels remained in the normal range across most of the Chalk aquifer. A similar picture characterised levels in a number of minor aquifers (e.g. the Norfolk Drift and Essex Gravels). The 2003 spring recession was particularly steep in the limestone aquifers – at Ampney Crucis in the Jurassic limestone of the Cotswolds only during the 1976 and 1984 droughts have lower May levels been recorded. Steep spring declines were evident in the more responsive Permo-Triassic sandstones units but, generally, the large storage within the aquifer – which militates against rapid change – meant that levels were still well above the early summer average.

June

With evaporative demands again well above average over wide areas soils in most most aquifer outcrop areas were exceptionally dry by late June. Infiltration during June was thus largely confined to very localised episodes associated with notable storm rainfall totals (e.g. a modest increase in groundwater levels was reported for the Carboniferous Limestone at Alstonfield in the north Midlands). Generally however the spring/ summer recessions continued – by month-end levels in parts of the western Chalk (e.g. at Woodyates and Chilgrove) had fallen around 30m from their January maxima, and were appreciably below the average for early July. But levels in the majority of index wells in the Chalk were still well within the normal early summer range. Although a similar generalisation applied to most limestone outcrops, however, late-June levels at Ampney Crucis in the Cotswolds were the lowest since June 1997. Following more than two years above previous seasonal maxima in some areas (e.g. North Wales), the 2003 recession returned levels in most of the Permo-Triassic sandstones aquifer to the normal range, albeit still well above average in the northerly outcrops. Levels in the minor aquifers of eastern England continued to follow a typical summer recession.

July

Notwithstanding the late July rainfall, soil moisture deficits were considerably above average across most major outcrop areas by month-end, and increased further in early August. Infiltration during July was, as usual, minimal and groundwater level recessions continued in all the major aquifers. Recessions in the Chalk generally followed a typical shallow summer decline but groundwater levels in the most southerly outcrops were depressed. Levels were also well below the average in the Jurassic Limestone of the Cotswolds but generally within the normal range in the other limestone aquifers. In the Permo-Triassic sandstones, levels in the Llanfair DC and Heathlanes index boreholes closely approached the average for first time since 1999; the Yew Tree Farm hydrograph also exhibited a sustained decline but had only recently fallen below pre-2000 maxima. Overall groundwater resources for England and Wales were around the average for the time of year.

August

As is normally the case, many of the highest late summer soil moisture deficits coincided with the outcrop areas of the major aquifers. Correspondingly, the summer groundwater level recessions continued – leaving levels particularly depressed in parts of the southern Chalk. At Compton (in the South Downs), where levels have been measured since 1894, lower August levels have only been recorded during the severe drought of 1975/76. Chalk levels were also low in Northern Ireland but throughout the greater part of the outcrop they remained within the normal late summer range. Levels in the limestone aquifers similarly remained within the normal range but considerably below average whilst levels remained healthy throughout almost all of the Permo-Triassic sandstones outcrops. At month-end, soil moisture deficits were the equivalent of more than12 weeks residual rainfall (rainfall-actual evaporation) in some eastern areas – further declines in groundwater levels were therefore inevitable.

September

With record soil moisture deficits across many outcrop areas, infiltration during September was again minimal and the, already protracted, 2003 groundwater level recessions continued. Groundwater levels were especially depressed in parts of the southern Chalk whilst, to the east and north, levels in the Chalk remained considerably healthier – still above average in parts of the Chilterns and mostly within the normal early autumn range elsewhere. Generally, the limestone aquifers presented a similar picture, as did a number of the minor eastern aquifers (e.g. the Essex gravels and Norfolk Drift). Levels in most of the southern Permo-Triassic sandstones outcrops also remained within the normal range but the slower-responding Midland and northern outcrops were still close to pre-2000 maxima, albeit at their lowest for four or five years in most cases.

October

Rainfall over most outcrop areas was above average in October and soil moisture deficits decreased briskly around month end. However, deficits were still amongst the highest on record (for October) across most aquifer outcrop areas; consequently recharge was minimal. The absence of significant recharge over the Feb-Oct period had produced a dramatic decline in groundwater levels – one with few modern parallels (1995 was comparable). But there were important spatial variations in the health of groundwater resources. In the south-western Chalk, water-tables in some areas were approaching natural base levels (e.g. at Chilgrove) and a number of wells had been reported as dry. To the east and north, groundwater levels in the Chalk were mostly below average but still within the normal range; a few (e.g. in the Chilterns) remained a little above average. The delayed onset of the 2003 seasonal recovery was particularly evident in the limestone aquifers where October levels were generally well below average – but still considerably above drought minima. This was true of many minor aquifers also, and most boreholes in the slower responding Permo-Triassic sandstones outcrops reported levels within the normal late-autumn range. However, concern focused on the possibility that the 2003/04 recharge season could be further truncated by limited rainfall over the late autumn.

November

Late-October and early-November rainfall rapidly reduced outstanding soil moisture deficits allowing infiltration to recommence in some of those areas where the water-tables were most depressed (the southern Chalk especially). But soils remained seasonally very dry across parts of the Midlands, Yorkshire and East Anglia (coastal areas of north-east Britain also). Reporting dates for many index boreholes meant that the full effect of the late-November infiltration was not evident on the November groundwater level traces. Nonetheless, groundwater level increases were recorded (from a very low base) at index wells in the Jurassic Limestone, Magnesian Limestone and in the south-western Chalk. Recessions continued across much of the rest of the Chalk outcrop – at Chilgrove, late-November levels were the 3rd lowest in a continuous series from 1836. The degree of water-table depression was more modest to the north but, generally, levels in the Chalk were below any recorded since 1996 or 1997. This was also true of the more responsive Permo-Triassic sandstones outcrops but levels remained very healthy across most of the outcrops – although spatial variations were large reflecting differing recharge patterns and aquifer characteristics. Overall groundwater resources were considerably below average for the autumn but significantly healthier than at the same time in 1995 and 1996.

December

The frontal rainfall, mostly of modest intensity, during December helped to consolidate the groundwater recovery that had gathered momentum in the late autumn. A significant proportion of index wells reported too early in December to fully capture the consequent groundwater level recovery but notable rises were reported for a number of responsive aquifer units (particularly in the limestone aquifers, but in the Isle of Wight Chalk also). The upturn in the southern Chalk was especially welcome and levels in most index wells and boreholes returned to within the normal range – albeit still low for the early winter. Even in the normally late-responding eastern aquifer units (e.g. the Essex Chalk), and in the minor aquifers (e.g. the Suffolk Crag) modest rises were recorded in December. In the context of the abundant 1998-2002 recharge, the paucity of 2003 infiltration to the slowest responding Permo-Triassic sandstones outcrops is of limited significance – levels in most index wells remained above average at year end. Near-saturated soils in almost all outcrop areas ensured that further significant infiltration would occur in early 2004.

References

1. Manley, G. (1974) Central England Temperatures: monthly means 1659 to 1973. Quart. Jour. Roy. Met. Soc. 100, 389-405.

2. Hough, M., Palmer, S., Weir, A., Lee, M. and Barrie, I. (1995) The Meteorological Office Rainfall and Evaporation Calculation System: MORECS Version 2.0. An update to Hydrological Memo. No. 45, Met Office.

Location Map

nrfa@ceh.ac.uk
www.ceh.ac.uk